(4)

RADC-TR-89-363
Final Technical Report
February 1990

AD-A219 941

FASTER: THE FAULT TOLERANT ARCHITECTURE SIMULATION TOOL FOR EVALUATING RELIABILITY, INTRODUCTION AND APPLICATIONS

Sanders Associates, Inc.

Sponsored by
Strategic Defense Initiative Office

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the Strategic Defense Initiative Office or the U.S. Government.

Rome Air Development Center
Air Force Systems Command
Griffiss Air Force Base, NY 13441-5700

90

This report has been reviewed by the RADC Public Affairs Division (PA) and is releasable to the National Technical Information Services (NTIS) At NTIS it will be releasable to the general public, including foreign nations.

RADC-TR-89-363 has been reviewed and is approved for publication.

APPROVED: Joseph A. Caroli

JOSEPH A. CAROLI
Project Engineer

APPROVED: John J. Bart

JOHN J. BART
Technical Director
Directorate of Reliability & Compatibility

FOR THE COMMANDER: James W. Hyde III

JAMES W. HYDE III
Directorate of Plans & Programs

FASTER: THE FAULT TOLERANT ARCHITECTURE SIMULATION TOOL FOR EVALUATING RELIABILITY, INTRODUCTION AND APPLICATIONS

P. Zemany
D. Goller

Contractor: Sanders Associates, Inc.
Contract Number: F30602-85-C-0317
Effective Date of Contract: 16 September 1985
Contract Expiration Date: 31 December 1988
Short Title of Work: FASTER, Intro & Applications
Period of Work Covered: Oct 85 - Jan 89

Principal Investigator: Terry Ginn
Phone: (603) 885-9193

RADC Project Engineer: Joseph A. Caroli
Phone: (315) 330-4205

Approved for public release; distribution unlimited.

This research was supported by the Strategic Defense Initiative Office of the Department of Defense and was monitored by Joseph A. Caroli, RADC (RBET), Griffiss AFB NY 13441-5700 under Contract F30602-85-C-0317.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS N/A
2a. SECURITY CLASSIFICATION AUTHORITY N/A 2b. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
4. PERFORMING ORGANIZATION REPORT NUMBER(S) N/A	5. MONITORING ORGANIZATION REPORT NUMBER(S) RADC-TR-89-363
6a. NAME OF PERFORMING ORGANIZATION Sanders Associates, Inc. 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION Rome Air Development Center (RBET)
6c. ADDRESS (City, State, and ZIP Code) Software Systems Engineering 95 Canal Street Nashua NH 03061	7b. ADDRESS (City, State, and ZIP Code) Griffiss AFB NY 13441-5700
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Strategic Defense Initiative Office 8b. OFFICE SYMBOL (If applicable) SDIO	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F30602-85-C-0317
8c. ADDRESS (City, State, and ZIP Code) Office of the Secretary of Defense Wash DC 20301-7100	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO: 63223C PROJECT NO: B413 TASK NO: 03 WORK UNIT ACCESSION NO: 23

11. TITLE (Include Security Classification)
FASTER: THE FAULT TOLERANT ARCHITECTURE SIMULATION TOOL FOR EVALUATING RELIABILITY, INTRODUCTION AND APPLICATIONS

12. PERSONAL AUTHOR(S)
P. Zemany and D. Goller

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM Oct 85 TO Jan 89	February 1990	138

16. SUPPLEMENTARY NOTATION
N/A

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	
13	08		Reliability Modeling; Mean-Time-Between-Critical-Failure; Reliability Evaluation; Availability; Fault Tolerance

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

FASTER is a Monte Carlo Simulator which is used to evaluate reliability figures of merit for complex reconfigurable fault tolerant systems. The process used to specify a complex system is simplified with the use of constraint directed editors. The editors ease the interactive process which guides the user through system configuration and mission scenario input. Complete and well defined system specifications are produced as a result of the interactive constraint directed editors. The FASTER program was designed to be flexible, and thus allows for the modeling and evaluation of a wide range of fault tolerant system types and considerations. For example, FASTER can account for the effects of both active and standby redundancy, imperfect switching and diagnostics, multiphase mission scenarios, and various maintenance and repair philosophies such as scheduled preventive, immediate or deferred maintenance. Figures of merit calculable by the FASTER program include, but are not limited to, reliability, availability, mean-time-between-critical-failure (MTBCF), MTBF, and mean-time-to-repair (MTTR).

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL JOSEPH A. CAROLI	22b. TELEPHONE (Include Area Code) (315) 330-4205 22c. OFFICE SYMBOL RADC (RBET)

DD Form 1473, JUN 86 Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

Contents

Executive Summary

FASTER (Fault Tolerant Architecture Simulation Tool for Evaluating Reliability) provides a flexible method for simulation of complex reconfigurable systems subject to different mission phases. This report describes the following: 1) Method of representation for complex systems, 2) Editors used to enter system representation, 3) FASTER simulation method and 4) Examples.

FASTER was developed to describe complex systems which can not be easily addressed with analytical techniques. The unique features of FASTER are the method of representation and the constraint directed editor.

FASTER is written in FORTRAN and can run on a VAX series computer.

1 Introduction

This report describes technical features of the FASTER simulation package. The concepts used in the design of FASTER are discussed. Also, because FASTER deals with complex reconfigurable systems, a method and approach for effective system representation is presented. This representation method is needed because more traditional methods such as analytical techniques which combine subsystem MTBFs to obtain an overall MTBF (or combine other quantities such as availability or reliability) are not able to easily deal with complex reconfigurable systems. A clear understanding of this representation method is needed to properly use FASTER.

The report is divided into the following sections:

2.0 Representation of Complex Reconfigurable Systems

3.0 Constraint Directed Editor

4.0 FASTER Engine

5.0 Modeling Capabilities-Examples

Each of the above sections provide background for the FASTER user. Further details and examples on how to use FASTER are provided in the FASTER User's Guide.

2 Representation of Complex Reconfigurable Systems

Existing methods for computing reliability characteristics of fault tolerance systems are effective for simple systems. There are analytical techniques for computing failure rates of simple series and parallel systems. However, when the system can reconfigure by changing its internal state or use of reallocation of resources, the analytical methods quickly become overly complex and almost impossible to solve in closed form. Furthermore, complex systems performance is typically dependent on the mission. The ability of the system to successfully complete its mission is the important question instead of what is the failure rate.

2.1 Need for a Mission Level Simulation

For a complex system which can adapt in response to internal failures, the important question is:

Can the system complete its intended mission?

This is in contrast to the normal measures (such as failure rates) which are used for simple systems. For this reason, the environment (or mission) of the complex system needs to be described. Many missions place time dependent loads or demands on the system. This has two effects:

1. Stress levels placed upon the system change.

2. System performance requirements change.

Both of these effects must be considered in the evaluation of complex systems. Different stress levels change the MTBF of various subsystems and cause failures to be correlated with different mission phases. Time varying requirements imposed by the mission require different levels of system availability. For these reasons, the FASTER system has a "mission block" which is used to specify time dependent scenarios which "drive" the system simulation.

The mission block can be used to represent times when certain resources are needed. Also, the mission defines what function the system must conduct. The success of the system is dependent on the coincidence of having the right resource at the right time. If resources are unavailable during periods when they are not needed, then the mission may still be successful.

2.2 System Representation

Complex systems are composed of multiple interacting subsystems. The interaction between subsystems determines how the overall system functions. Also, complex systems, subject to failure and other changes in condition, must be described by a dynamic process. At any instant in time, the system can be described by a state. The overall state of the system is a function of the states (or modes) of the subsystems. The mode of a subsystem determines its ability to function. For example, if a subsystem is in a failure state, the subsystem "output" may not have the desired responses to other systems "input". Other subsystems may not be able to perform their function because of the interaction with the

failed subsystem. That is, subsystems which have not failed may still not be operational because they do not have the required inputs.

To deal with subsystem interactions and effects of different subsystem modes, FASTER represents complex systems by using a state transition diagram and high level "functional" transfer functions associated with each node (or state or mode) in the state transition diagram. Figure 1 shows how a system is represented as a set of interconnected subsystems. Note that each subsystem has a mode and each mode has an associated functional transfer function. The combination of state transitions and functional transfer functions form the basic unit of subsystem representation in FASTER. This type of subsystem is referred to as a primitive.

A complex system can be composed of many primitives which interact through connections or interfaces.

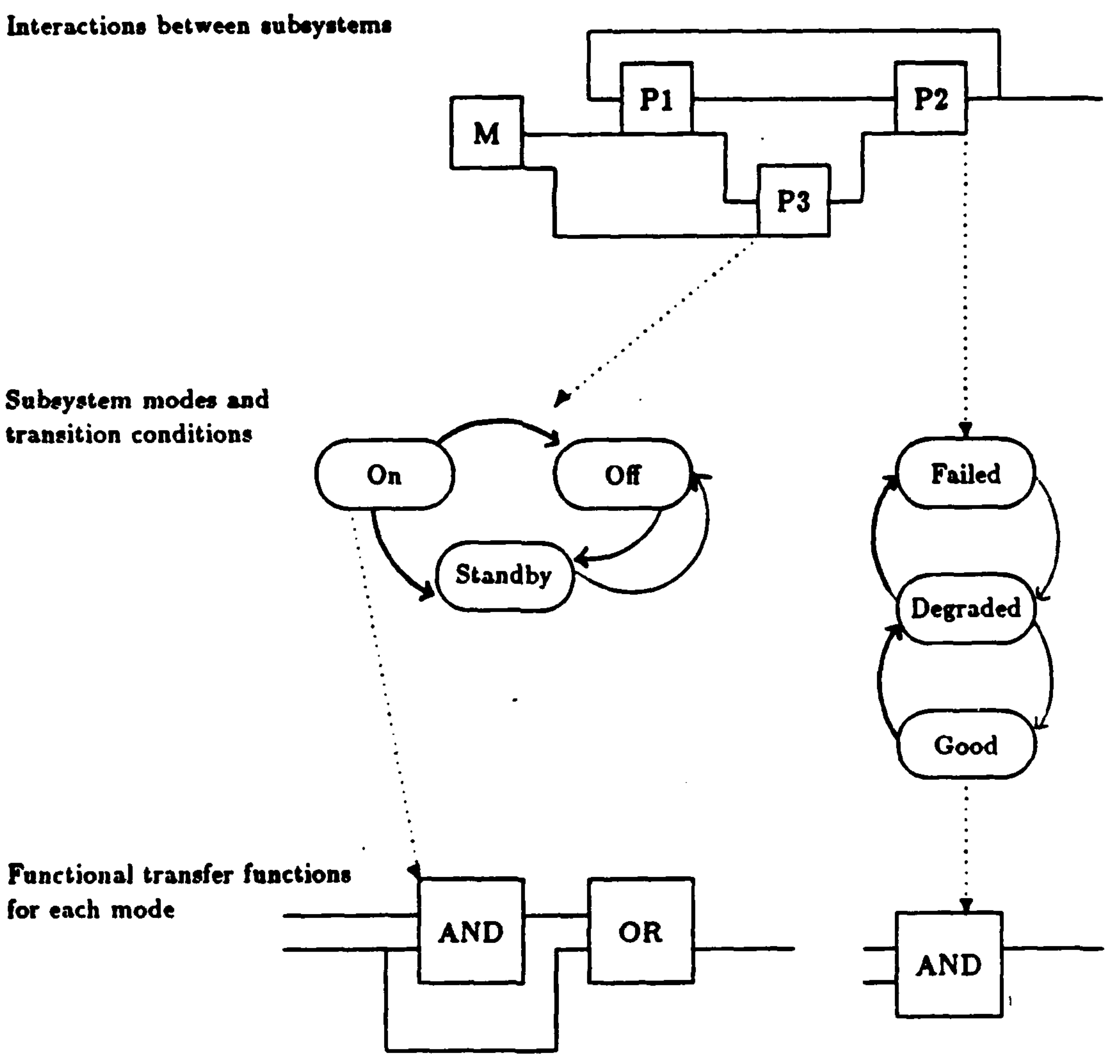
The above representation method was chosen to allow FASTER to describe complex reconfigurable system behavior; some features of this representation are:

1. The number of system modes is given by a product of the numbers of subsystem modes. This makes it impractical to construct an overall system state diagram in many cases. The FASTER representation method allows the user to partition the system into interacting subsystems. An overall state transition diagram is not entered by the user, instead, state transition diagrams for each subsystem are entered. For a system composed of 10 subsystems having 5 modes/subsystems an overall state diagram would have 5**10 modes because of combinatorial effects. However, if 5 diagrams with 10 modes each are used to represent the system, the user only needs enter 50 modes each instead of one diagram with 9,765,625 modes which would be required if one transition diagram was used to describe the system.

2. The use of "functional" transfer functions allows the interactions between subsystems to be described in terms of input resources and output resources. Subsystems may not be able to perform their function if they do not receive the proper input resources from other subsystems. This feature allows a "richer" description of subsystem interoperability and a relation to a mission scenario.

3. The description allows "feedback" from one system to another. Feedback is required if a system is self reconfigurable. Also FASTER can account for the effect of imperfect Built-in-Test (BIT) and switching. Certain primitives which act as monitors (BIT) and control switches can be defined and used to describe reconfigurable systems. Feedback is involved when monitor output is used to cause reconfiguration.

REPRESENTATION



Each subsystem has a mode graph and each mode in the mode graph has a functional transfer function.

Figure 1: FASTER Representation

4. Unlike the analytical approach, a FASTER model closely relates to the systems being simulated. This makes it easier for the user to understand the modeling process and see how the relationships between subsystems impact overall system performance.

The representation method requires a system engineering approach. To use FASTER properly, the interactions between subsystems must be understood by the FASTER user. The FASTER editors allow users to define primitives and describe subsystem interactions without using a specialized computer language. Figure 2 is an illustration of the types of data needed in a FASTER simulation. A brief description of the data is presented in figure 2. Further details can be obtained from the users guide as well as in section 5.

2.3 System Performance Measures

Traditional measures used include Mean Time Between Failure (MTBF), Mean Time Between Critical Failure (MTBCF), Mean Time to Repair (MTTR), availability and reliability. In a simple system only one value for each of the above measures is needed. However, for complex systems, there may be several numbers or values which relate to each of the above measures. For example a complex system which performs multiple functions may have a MTBCF for each function. Furthermore, each of the above measures must be extended or generalized. For example, MTBF, MTBCF and MTTR can be extended to Mean Time Between Transition. This extension is required because there may be several failure modes involved in a complex system. In some cases, the meaning of "failure" must be defined. For a complex system, the failure of subcomponents is not the prime quantity of interest. Instead, the quantity of interest is the failure of the system to perform mission objectives. Individual subcomponent failures may still be of interest to system designers who must determine the required redundancy.

For highly complex systems, the user can use the "test probe" approach to obtain statistics for only selected subsystems. This "test probe" approach is needed in order to control the amount of data generated. Figure 3 shows an example of FASTER output. The first part of the output is a list of the selected subsystems, transition types, and transition specifications. There are several transition types. Failure is only one kind of transition other types include delay/warm up, and control.

The next part of the output gives the following:

Average time in mode	Availability
Standard Deviattion	Unavailability
Number of non-zero-runs	Reliability

1. **Number of Modes**

2. **Number of Transitions**

3. **Transition list (type, from mode, to mode)**
   - **Failure rate–failures/unit time**
   - **Delay time–transition time delay**
   - **Control source–input number which drives control transition**

4. **Transfer functions defined for each mode:**
   - **Number of subprimitives**
   - **Connection list–defines how subprimitives are connected**
   - **Parameter and limit values–numeric values for subprimitives**

Figure 2: Data Which is Used in FASTER Primitives

```
SIMULATICN RESULTS

Simulation name: fdbk_sim
Number of simulation runs: 1CC0
Single run duration: 50000.0C
Number of monitored primitives: 10
Random number seed: 1212121

PRIMITIVE DESCR.          TRANSITION       TRANSITION AND MODE DESCRIPTION
 NO NAME                  TYPE             FROM MODE(NO/NAME)         TC MODE(NO/NAME)
  2 fdbk_power            control          1 fail                     2 on
                          failure          2 on                       1 fail
  3 fdbk_power            control          1 fail                     2 on
                          failure          2 on                       1 fail
  8 fdbk_repair           delay/warmup     1 repairing                2 idle
                          control          2 idle                     1 repairing
  9 fdbk_repair           delay/warmup     1 repairing                2 idle
                          control          2 idle                     1 repairing
 11 lib_timer             control          1 down                     2 up
                          control          2 up                       1 down

PRIMITIVE                  MODE   AVERAGE      STANDARD       NON-0    AVAILABILITY     UNAVAILABILITY    RELIABILITY
  NO NAME                   NO       TIME     DEVIATION        RUNS
  2 fdbk_power               1   7.72E+03  7.57817612E+01    10C0   1.54435123E-01   8.45564877E-C1   0.0C000C00E+CC
                             2   4.23E+04  7.57817612E+01    1000   8.45564877E-01   1.54435123E-C1   0.0C000C00E+00

  3 fdbk_power               1   7.71E+03  7.32811813E+01    10C0   1.54209761E-01   8.45790239E-C1   0.0C000C00E+00
                             2   4.23E+04  7.32811813E+01    10C0   8.45790239E-01   1.542C9761E-C1   0.0C000000E+00

  8 fdbk_repair              1   4.22E+03  1.84564037E+01    10C0   8.44225804E-02   9.15577420E-C1   0.0C000C00E+C0
                             2   4.58E+04  1.84564037E+01    10C0   9.15577420E-01   8.44225800E-C2   0.0C000C00E+00

  9 fdbk_repair              1   4.25E+03  1.8592C715E+01    1000   8.49248103E-02   9.15C75190E-01   0.0C000000E+C0
                             2   4.58E+04  1.85920715E+01    1000   9.15C75190E-01   8.49248099E-02   0.0C000C00E+00

 11 lib_timer                1   1.01E+03  8.26933002E+00    1000   2.02243956E-C2   9.79775604E-C1   0.0CC00C00E+00
                             2   4.90E+04  8.26933002E+00    1000   9.79775606E-01   2.02243945E-02   0.0CC00G00E+00

PRIMITIVE                  TRANS.  TOTAL NO  NON-ZERO  MEAN TIME     RELIABILITY       UNRELIABILITY
  NO NAME                  FR  TO  OCCURNCS      RUNS  BETW TRNS
  2 fdbk_power              1   2     42170      1000   1.19E+C3   0.CC000000E+00    1.0C000000E+0C
                            2   1     42328      1000   1.18E+03   0.CC000000E+C0    1.C0CC0000E+CC
  3 fdbk_power              1   2     42426      1000   1.18F+03   0.CC000000E+00    1.C0000000E+0C
                            2   1     42576      1000   1.17E+03   0.CC00C000E+00    1.C0000000E+0C
  8 fdbk_repair             1   2     42170      1000   1.19E+C3   0.CC00C0C0E+C0    1.C00C0000E+0C
                            2   1     42253      1000   1.18E+C3   0.CCC0C0C0E+C0    1.C0CC0000E+0C
  9 fdbk_repair             1   2     42426      1000   1.18E+C3   0.CC000000E+00    1.0C000000E+0C
                            2   1     42507      1000   1.18E+C3   0.CC00C000E+00    1.00000000E+00
 11 lib_timer               1   2     13234      1000   3.78E+03   0.CC000000E+00    1.C00C0000E+0C
                            2   1     13257      1000   3.77E+03   0.0C000000E+00    1.C0000000E+00
```

Figure 3: Example FASTER Output

The *operational state* of the system can be defined by using "and" and "or" primitives, and a timer probe. The timer probe has two modes which can represent system up or system down. The availability of a given mode is the fraction of time that the system is in the mode during the mission. If the mode corresponds to an operational condition of the system, then it can be interpreted as system availability.

To compute reliability, the actual mission length must be used as the run time. The reliability is then given by *number of missions without a critical failure*/number of runs. The FASTER output computes this quantity. Examples in section 5 show how to interprete the FASTER output to obtain reliability.

To obtain MTBF and MTBCF, the mean time between transition (MTBT) values are used. In cases when the transition represents a loss of a critical system function, MTBF is actually the MTBCF. Since the system may have multiple functions, many MTBT values are obtained. The user must, therefore, define which transition represents *critical failures*. To define a single MTBCF, a timer block which monitors a set of "or" blocks which, in turn, detect any critical failure is used.

3 Constraint Directed Editor

The editors in FASTER are used to obtain the data which defines the simulation. To manage this process, the editors are set up to present displays to the user which define or indicate what type of information is needed. The specification process is interactive and dynamic. As the process unfolds, the "needed information" requirements change or can be further identified. For example, the user first specifies a set of subcomponents and from this list of subcomponents, the editor determines the interfacing requirements and generates a display which indicates the data needed to "wire up" the subcomponents. Also, the editor identifies if any parametric information is needed by examining the subcomponents in the user specified list. The user interacts with the editor by supplying the requested information. In some cases, satisfaction of one prompt may result in the generation of secondary prompts.

This approach leads to a simplified specification process. The user responds to the editors prompts until the editor has no more questions. Then the specification is complete. In a traditional specification language, the user can make errors of omission. However, the interactive process used by the FASTER editors prevents this. The user can then concentrate on creating realistic simulations instead of the syntax of a specification language.

There are two major editors in FASTER which are used to define the simulation. These are the "primitive editor" and the "*top level editor*".

The primitive editor is used to define FASTER primitives which represent the subcomponents of the system being simulated.

These basic subcomponents (referred to as primitives) consist of a state (or mode) transition diagram and a functional transfer function associated with each state or mode in the transition diagram. Below is a summary of the information contained in a primitive:

1. Names of each state or mode in the state transition diagram.
2. Exit conditions for each state in the transition diagram (failures, control line, warmup, etc.).
3. Functional transfer functions for each state in the transition diagram.

The primitive editor obtains this information from the user. For "exit conditions", the primitive editor requests appropriate information which is dependent on the specific exit condition selected. For example, if the exit condition is a "failure", the editor requests which failure equation is to be used. If a constant failure is selected, the editor then

requests a single number relating to the MTBF. If a non-constant distribution is used, the editor will prompt the user for a set of numbers which represent the distribution of failures. Thus, the editor guides the user by identifying what type of information is needed.

The primitive editor also requires that the user describe a transfer function for each mode in the graph. A transfer function is formed by selecting a set of operators from a list of simple logic and threshold functions. To assist the user, the primitive editor prompts the user for connection data which describes how to combine the selected elements. The resulting primitives are stored on a disk file for later use by the high level editor. An example of the operation of the primitive editor is presented in the users guide.

FASTER also has a mission editor which is used to define a scenario or mission for the system being simulated. The user specifies the "external" inputs to the system being simulated. Examples of external inputs are control inputs (which turn the system on and off) and mission load.

The "Top Level Editor" is used to combine primitives together to form the system to be simulated. In a fashion similar to the primitive editor, it generates displays which indicate what information or inputs are to be supplied to the user. This information deals with connections and interfacing the primitives together.

4 FASTER Simulation Function

The FASTER Simulation Function is shown in Figure 4. The heart of the simulation is the function called the FASTER Engine. Because this function is best understood in terms of a virtual machine, it will be referred to as the FASTER Engine. Section 4.1 describes the FASTER Engine in detail.

The other functions shown in Figure 4 are used for set up and control of the FASTER Engine. Since FASTER does Monte Carlo simulations, the number of runs through a mission must be specified. The initialization function obtains this information from the user. Also, the initialization function must obtain from the user the file name of a file which defines the "program" for the Engine. Furthermore, it must "down load" the program. This down loading process is referred to as "building the internal representation".

At this point, the Engine is ready to simulate. The simulation control function causes the engine to carry out the specified number of simulation runs. Each run corresponds to one mission period. At the end of the run, the engine must be restored to the "start of mission" initial condition. Also, run summary information may be recorded. To carry out these tasks, the simulation control function uses functions called "run set up" and "copy initial conditions".

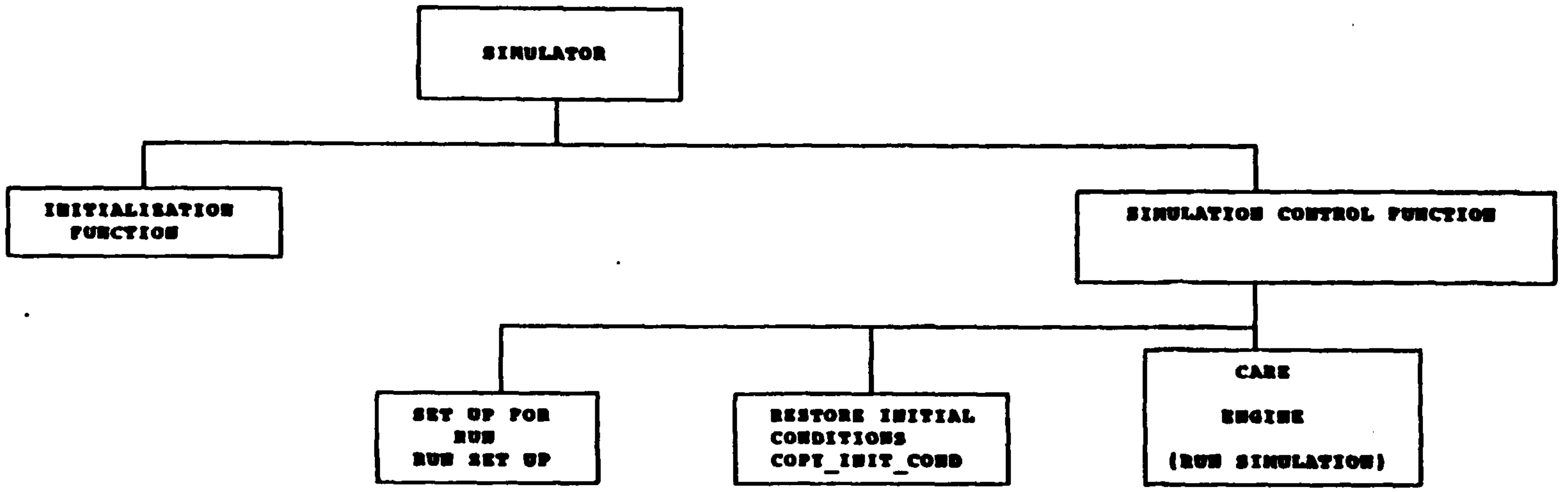


Figure 4: FASTER Simulation Function

4.1 FASTER Engine

This section describes the FASTER Engine. The set up and control functions involved to initialize the Engine and carry out a number of Monte Carlo runs were discussed at a high level in the previous section. The following paragraph describes how the FASTER Engine can be viewed as a virtual machine. Comparisons between a standard processor and the FASTER Engine are made. The approach used in the FASTER Engine was selected in order to achieve the flexibility needed in modeling complex reconfigurable systems. This design permits an object oriented approach that permits more complex representations of behavior to be easily added to the FASTER system.

The FASTER Engine is best viewed as a virtual machine which executes a program generated by the FASTER Editor. The program for the FASTER Engine consists of a data structure which specifies operators and addresses. Details of this data structure are shown in Figure 5. However, unlike the programs for existing computers, the operators and addresses used in FASTER are high level and relate directly to the problem domain. For example, some of the operators in FASTER are:

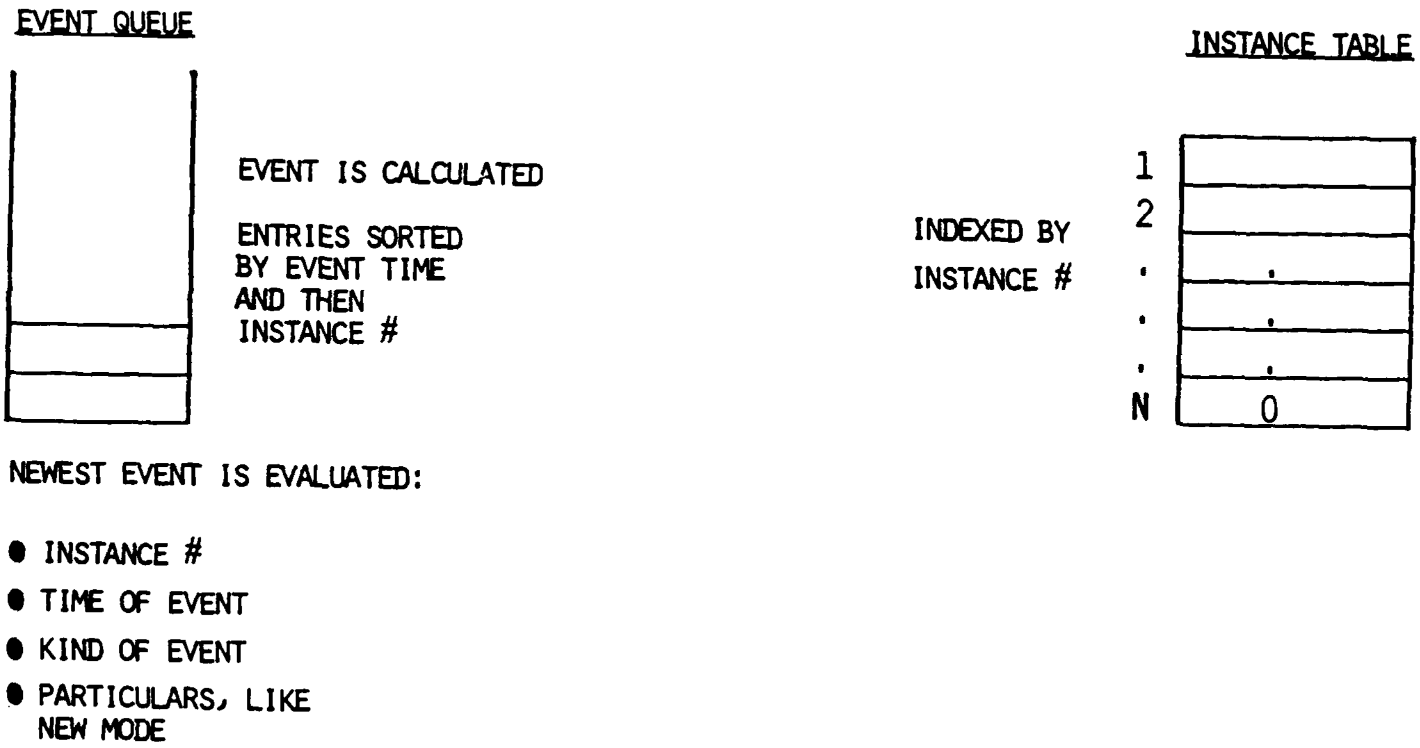
- Generate next failure event
- Generate repair event
- Evaluate transfer function

Figure 6 is an overview of the FASTER engine. Each operation in the FASTER engine is represented by FORTRAN code. This code is considered as part of the engine. The specific models defined by the user set up the data structure shown in Figure 5 which controls how the FORTRAN modules representing the various high level operators are executed.

The FASTER Engine is similar, in concept, to a standard processor. Note, however, that the FASTER Engine instructions represent considerably more complex data transformations than the instructions of a standard processor. In fact, FASTER instructions (primitives) are as complex as high level language programs containing three or four subroutines.

Examples of generic functions composing a primitive are:

- predict time of next failure



Data for each Instance

- A small table of outputs containing each output's current value
- A small table of inputs containing the instance # and output # of the connected primitive
- An encoded description of the mode transition diagram
- An encoded description of the transfer function for each mode
- The current mode and statistics for each mode
- Initial output, mode and statistical values

Figure 5a: Data Structure Overview

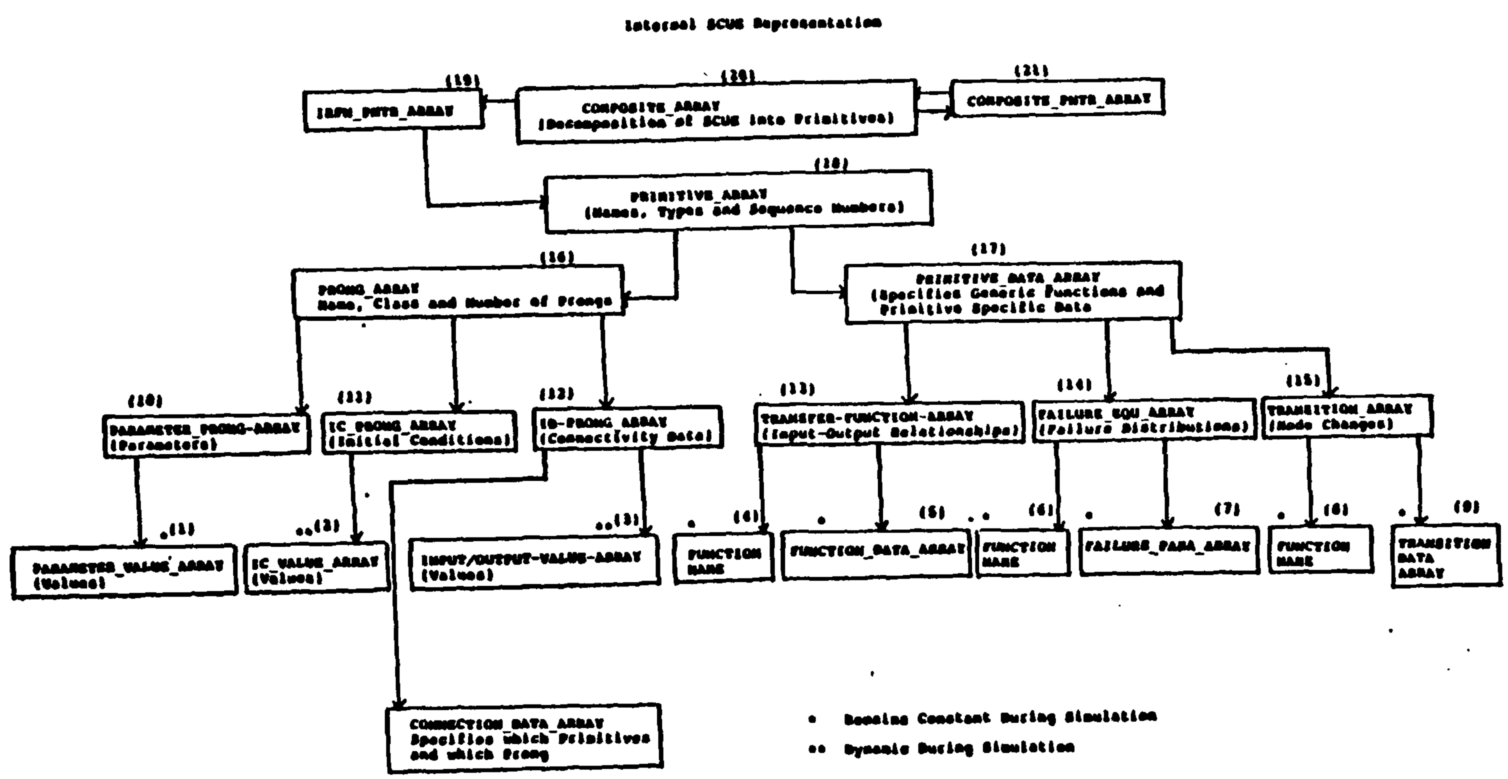


Figure 5b: Engine Data Structure

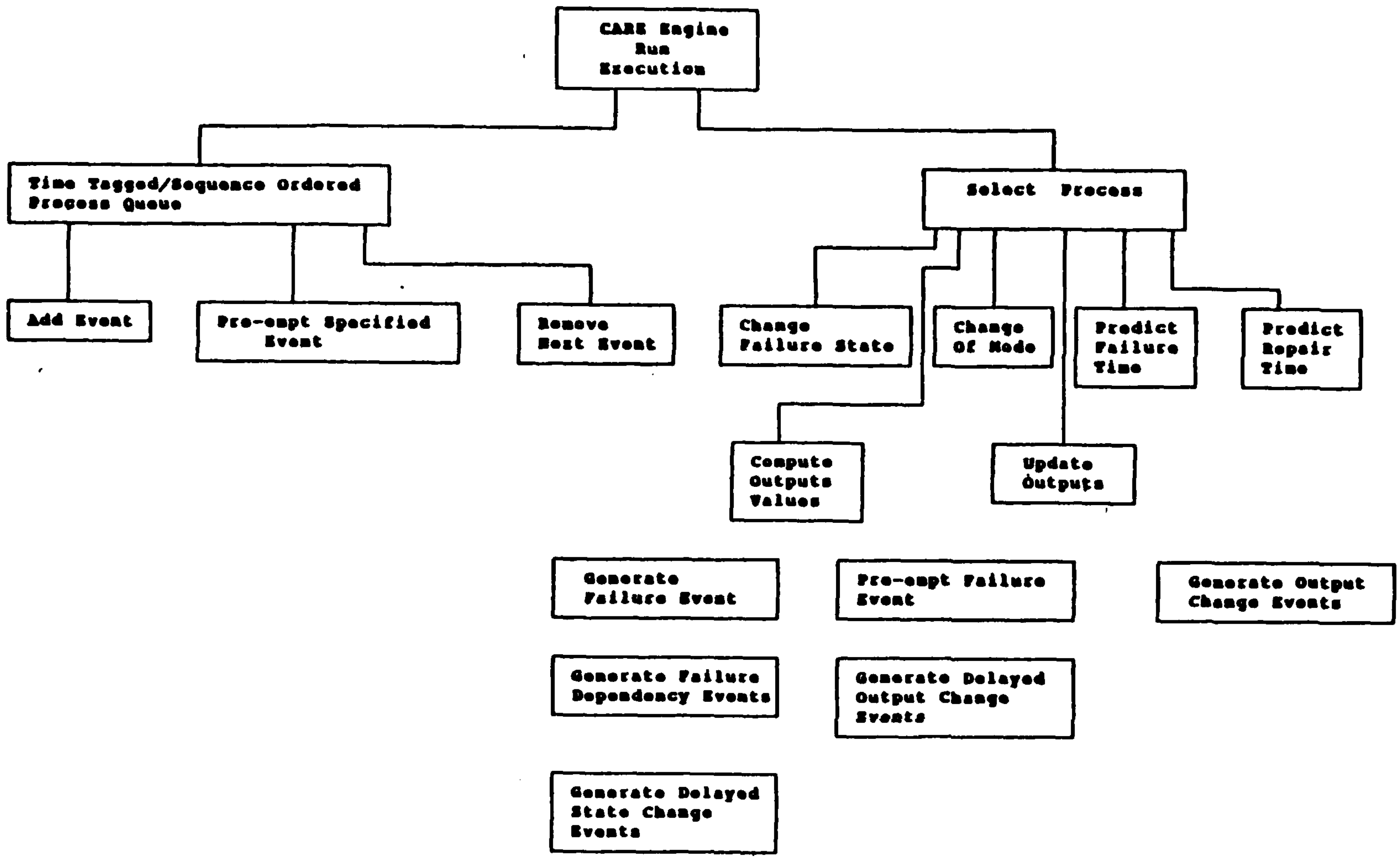


Figure 6: Engine Overview

- select new mode
- evaluate output

The FASTER Engine function is to control which instructions (actually Fortran subroutines) are executed. Execution of the instruction involves calling the appropriate generic functions.

The FASTER Engine instructions (which are FASTER primitives) differ in an important respect from instructions on a standard processor. This difference is that the FASTER instructions, which form a user specified simulation closely correspond to the real objects in the systems being simulated. This design permits an object oriented approach. Furthermore, in contrast to a standard processor in which an instruction-like "add" must have additional instructions to retrieve and store data from memory, the FASTER Engine does not specify address of data for its "instructions". Instead, the Engine only specifies an "instance" of an instruction which corresponds to an object in the system being simulated. The instance has all the information it needs to carry out the required data transformations. This includes the following:

1. List of input and output addresses. These pointers relate to how the instructions supply data to each other. They represent connectivity.
2. Specification of which generic functions to use. An instruction is carried out using one or more generic functions.
3. Pointers which specify data for the generic functions.

Note that in the above, items 1 and 3 are both pointers to data used by generic functions in 2. The difference between 1 and 3 is as follows: The addresses specified in 1 represent the connectivity or data transfer between primitives (instructions). The connectivity is defined by the user. This type of connectivity is directly related to how the components interact. The data specified in 3 represents instance specific information. In this way, a primitive editor can be used to form new primitives whose properties can be varied by changing data. Also, to allow the user to build primitives, the primitive editor allows the user to define which generic functions are to be used, as well as the data needed.

An important feature of the FASTER Engine is that it is set up to do event driven simulations. The "instructions" or primitives produce events which specify a time value and a specific instances of another instruction. The Engine stores these events in a queue for later execution. Thus, in the FASTER Engine, the instructions invoke (or call) each other.

The order of execution is determined by the time values and the connectivity. Connectivity enters in if two events have the same time value.

The FASTER Simulation Engine simulates the reliability behavior of a complex system. The system to be simulated is specified by the FASTER user (using the FASTER editor) as a composition of primitives. The primitives specify the appropriate high-level operations and data which need to be evaluated. The primitives interact with each other by updating states, updating outputs, and triggering actions (also called events). The Engine makes use of a linked list event data structure to store events, and/or messages. The Engine reads the list to obtain the next action or event which specifies a primitive. When an action is invoked upon the specified primitive, the primitive associated procedures are invoked using primitive specific data. The primitive is viewed as an "object of data" which specifies:

- Which procedure(s) to call in response to events and inputs.
- Primitive specific data for the procedure(s).

The Simulation Engine calls the specified procedures in a time-based sequence. The procedures use the primitive input data. The results of the execution of procedure are:

- Events which trigger other events may be generated.
- Output values may change and affect input values of other blocks.
- The state of the primitive may change.

A change in a given primitive's data/state affects other primitive(s), event(s) or triggers are generated for the affected primitive(s). These events are inserted into the time tagged list. Note that events must contain a time value and the name of the affected primitive. Upon receiving an event, affected primitives will examine the environment (which includes output values transmitted along connections) to determine how to respond. By responding to events by generating events for other primitives, the primitives drive the simulation. The process continues until the "end of run" event is processed.

An event type is specified in the event. The usefulness of specifying an event type as part of the event represents a tradeoff among the following factors:

- Complexity of source primitive vs. destination primitive processing needed to determine event type.

- Loss of generality when event types can only make sense in the context of the destination primitive (object-oriented approach does not need an event type).

Generic event types can be defined (e.g., output change, internal state change), and the source primitive will select the type. The destination primitive will interpret the event in its own context using the event type. Thus, both source and destination blocks will share in the task of determining how the destination block will respond.

The following classes of generic procedures are used:

- Control procedure which determine which subroutines or functions to call.
- State transition graph procedure.
- Failure generator (a random number generator and a parametric function will use primitive specific data to generate time of next failure. Also a branching ratio will be used if multiple mechanisms for failure are to be modeled).
- Input/output relationship processor (a generic interpreter will interpret primitive specific data in order to compute the primitive's outputs from the primitive's inputs (and possibly (in complex cases) the *current states*)).

The above procedures are considered part of the Engine. These procedures use "primitive specific data", "state data", and "interface data".

The "primitive specific data" is associated with a primitive even before the primitive is used to form a composite. The primitive also has "state data" and "interface data". The state data represents the condition of the primitive during the execution of the simulation. Execution of the procedures cause state data to change. The interface data represents how the primitives are "hooked up". The composite editor obtains the "hook up" information from the user. During simulation execution, this hook up (or interfacing) data will be used in a process to determine when a primitive will generate an event. Also the target of the generated events is determined by this interfacing data. As a general rule, events are sent by the source primitive to any primitive which is "hooked up" to some output value which was modified by the source primitive. Thus, for example, if primitive A's output is hooked to primitive B's input, primitive A sends an event to primitive B when primitive A related processing changes the said output.

The FASTER Engine (execute simulation function) consists of a time tagged event process queue function and a select process function (see Figure 6). The event Process queue

function selects the next event from the queue. This event points to a specific data object called a primitive. The said primitive data object contains data specifying how the primitive must respond to the event. Part of the primitive data object specifies generic procedures and this part will be used by the "select process" function which calls, in a data driven fashion, one or more of the generic processing functions. Other data which are used by the generic procedures are also contained in the primitive data object. Some of the generic processing functions generate data which form new time tagged events. If time tagged event data packets are formed, the "Add Event" function is used to insert new events into the time tagged queue. Figure 7 shows a representation of this processing flow. Underlined phrases highlight the actions carried out by the Simulation Engine.

Do Until Time Exceeds End Time

(1) Remove Next Event from Event Queue. This Event will specify the data of interest by specifying a pointer to a specific primitive.

(2) Based on Event type and changes in external data (input changes caused by actions produced by other primitives) select which processes must be executed. The selection process will be dependent on the primitive specific data, event type, primitive current state data, and interfaces with other primitives.

(3) Call Specified Processes.

(4) Update time using value in the event

(5) Insert any events into queue and remove any pre-empted events.

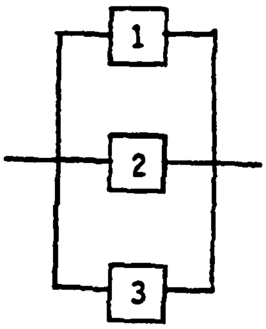
End Do

Figure 7: FASTER Engine

5 Modeling Capabilities – Examples

To use FASTER, the system properties must be translated into a representation that can define a FASTER simulation. This section presents some examples which illustrate how this is done. Each example is given in three parts. The first part is a top level description of the system from the users point of view. The second part is a brief discussion as well as a FASTER diagram of the system. The third part is the FASTER output. Details on how to enter the FASTER diagram are in the users guide. The objective of this section is to show examples of the ways systems can be represented by FASTER.

Example 1: Simple Active Redundancy (Deferred Repair). Repair Philosophy - Assume that corrective repair is deferred until a critical failure occurs. Repair occurs instantaneously at that time.



$\lambda_1 = \lambda_2 = \lambda_3 = .001$ failures/hr

1 out of 3 units required for success

Compute:

1. Mean-Time-Between-Critical-Failure (MTBCF)
2. Reliability at time t = 100 Hrs (R(100))

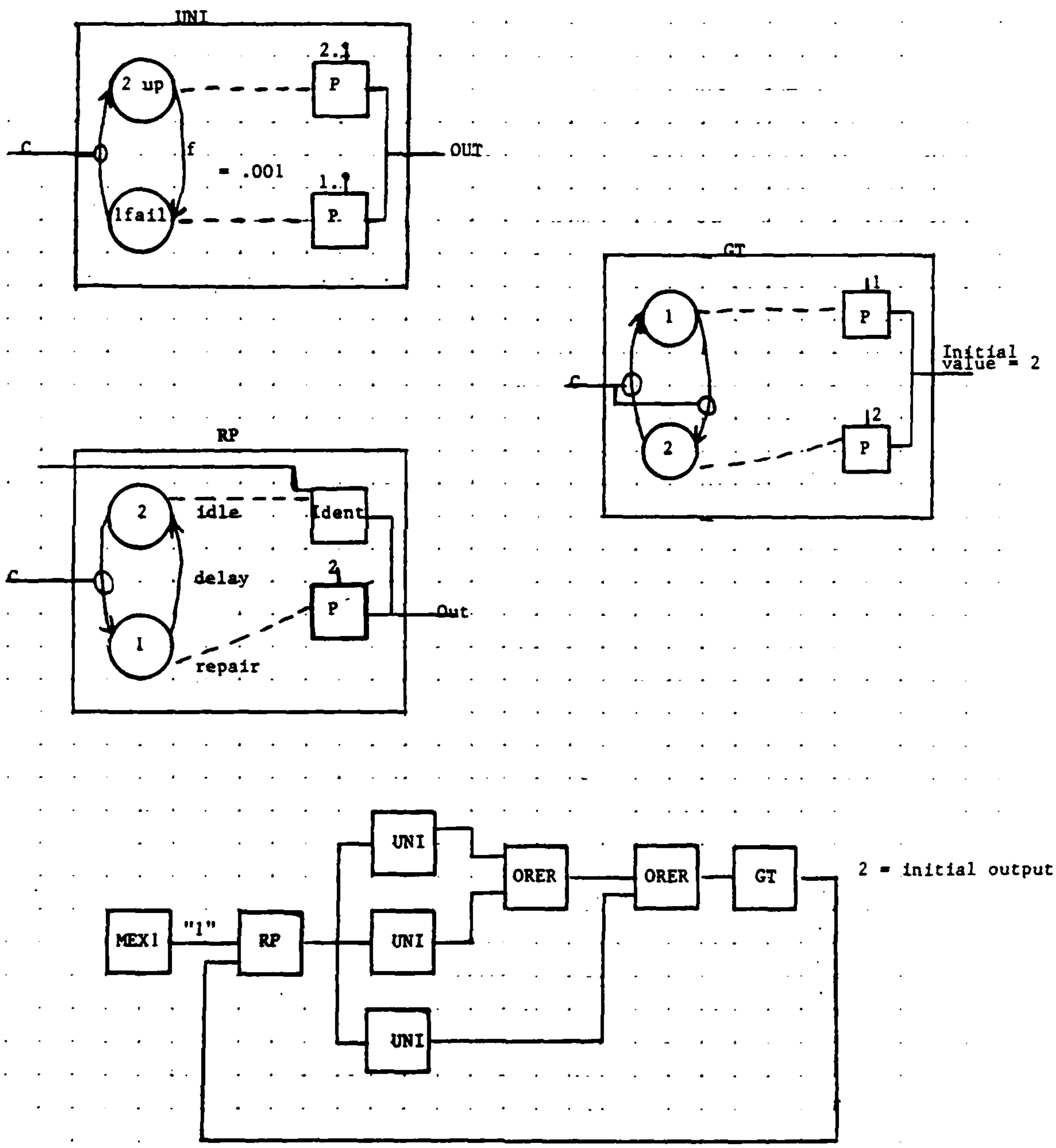
Example 1

FASTER can represent the system in several ways depending on user preference. Two FASTER simulation diagrams are shown for example 1. The first diagram closely parallels the system and was used to compute the system reliability. The reliability at T=100 hours is the probability that there will be no critical failures before 100 hours. Therefore, a 100 hour simulation was done. To obtain good statistics, 100,000 Monte Carlo runs were requested. The RP block gives the number of critical failures because it causes a repair action when a critical failure occurs. Inspection of the results show that there were 84 non-zero events for the repair process. The results also show that the system reliability is 0.99916.

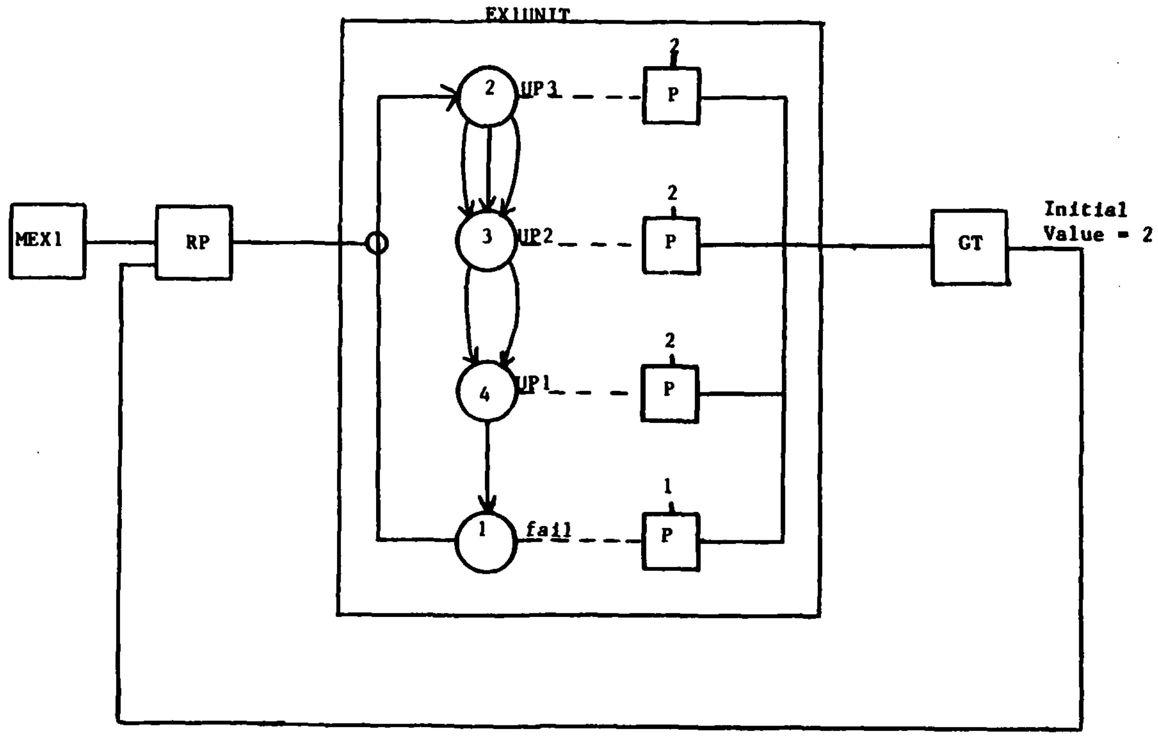
A second FASTER diagram was created. In this case, each mode relates to the number of subunits which are operational. When 3 units are up, the failure rate is three times the individual rate. As units fail, the failure rate out of the mode decreases. As in the previous case, reliability is obtained by requesting 100 hour missions. In this case the reliability was 0.9992.

To compute MTBCF, it is necessary to run a simulation with a very long mission time to assure that a critical failure occurs during every iteration. To obtain the MTBCF, the same simulation was run for a simulated time of 100,000 hours. The repair process which repairs the system when critical failures occur was deactivated. To do this, the input of EX1UNIT was directly connected to MEX1 so that no repairs can occur. A long mission time was requested to insure that a critical failure occurs for each run. With one critical failure per run, the MTBCF is given by the average time that the GT block spends in mode 2. Note that the GT block is a generic timer which keeps track of system mode. Inspection of the output shows that the MTBCF is 1840 hours.

EXAMPLE 1


UNI
2 up
1fail
f
= .001
2.
1.
P
P
C
OUT
GT
1
2
P
P
C
Initial value = 2
RP
2
1
idle
delay
repair
Ident
P
2
C
Out
MEXI
"1"
RP
UNI
UNI
UNI
ORER
ORER
GT
2 = initial output

Example 1



EX1UNIT
MEX1
RP
2
UP3
P
2
3
UP2
P
2
4
UP1
P
1
1
fail
P
GT
Initial
Value = 2

SIMULATION RESULTS

Simulation name: ex1
Number of simulation runs: 100000
Single run duration: 100.0000
Number of monitored primitives: 7
Random number seed: 12345

PRIMITIVE DESCR. NO NAME	TRANSITION TYPE	TRANSITION AND MODE DESCRIPTION FROM MODE(NO/NAME)	TO MODE(NO/NAME)
2 rp	delay/warmup	1 rep	2 idle
	control	2 idle	1 rep
3 uni	control	1 fail	2 up
	failure	2 up	1 fail
4 uni	control	1 fail	2 up
	failure	2 up	1 fail
5 uni	control	1 fail	2 up
	failure	2 up	1 fail
8 gt	control	1 one	2 two
	control	2 two	1 one

PRIMITIVE NO NAME	MODE NO	AVERAGE TIME	STANDARD DEVIATION	NON-0 RUNS	AVAILABILITY	UNAVAILABILITY	RELIABILITY
2 rp	1	8.40E-07	9.15626899E-08	84	8.39538574E-09	9.99999992E-01	9.99160000E-01
	2	1.00E+02	9.15283138E-08	84	9.99999992E-01	8.39500427E-09	9.99160000E-01
3 uni	1	4.78E+00	5.46358116E-02	84	4.78433707E-02	9.52156629E-01	9.99160000E-01
	2	9.52E+01	5.46358116E-02	9501	9.52156630E-01	4.78433704E-02	9.04990000E-01
4 uni	1	4.78E+00	5.45737296E-02	84	4.78298973E-02	9.52170103E-01	9.99160000E-01
	2	9.52E+01	5.45737296E-02	9438	9.52170103E-01	4.78298970E-02	9.05620000E-01
5 uni	1	4.84E+00	5.47952428E-02	84	4.84225744E-02	9.51577426E-01	9.99160000E-01
	2	9.52E+01	5.47952428E-02	9554	9.51577426E-01	4.84225741E-02	9.04460000E-01
8 gt	1	0.00E+00	0.00000000E+00	84	0.00000000E+00	1.00000000E+00	9.99160000E-01
	2	1.00E+02	0.00000000E+00	84	1.00000000E+00	-3.81472631E-13	9.99160000E-01

System Reliability

PRIMITIVE NO NAME	TRANS. FR	TO	TOTAL NO OCCURNCS	NON-ZERO RUNS	MEAN TIME BETW TRNS	RELIABILITY	UNRELIABILITY
2 rp	1	2	84	84	1.19E+05	9.99160000E-01	8.40000000E-04
	2	1	84	84	1.19E+05	9.99160000E-01	8.40000000E-04
3 uni	1	2	84	84	1.19E+05	9.99160000E-01	8.40000000E-04
	2	1	9503	9501	1.05E+03	9.04990000E-01	9.50100000E-02
4 uni	1	2	84	84	1.19E+05	9.99160000E-01	8.40000000E-04
	2	1	9443	9438	1.06E+03	9.05620000E-01	9.43800000E-02
5 uni	1	2	84	84	1.19E+05	9.99160000E-01	8.40000000E-04
	2	1	9557	9554	1.05E+03	9.04460000E-01	9.55400000E-02
8 gt	1	2	84	84	1.19E+05	9.99160000E-01	8.40000000E-04
	2	1	84	84	1.19E+05	9.99160000E-01	8.40000000E-04

SIMULATION RESULTS

Simulation name: example1
Number of simulation runs: 100000
Single run duration: 100.0000
Number of monitored primitives: 3
Random number seed: 12345

PRIMITIVE DESCR. NO NAME	TRANSITION TYPE	TRANSITION AND MODE DESCRIPTION FROM MODE(NO/NAME)	TO MODE(NO/NAME)
2 rp	delay/warmup	1 rep	2 idle
	control	2 idle	1 rep
3 exlunit	control	1 fail	2 up3
	failure	2 up3	3 up2
	failure	2 up3	3 up2
	failure	2 up3	3 up2
	failure	3 up2	4 up1
	failure	3 up2	4 up1
	failure	4 up1	1 fail
4 gt	control	1 one	2 two
	control	2 two	1 one

PRIMITIVE NO NAME	MODE NO	AVERAGE TIME	STANDARD DEVIATION	NON-0 RUNS	AVAILABILITY	UNAVAILABILITY	RELIABILITY
2 rp	1	8.00E-07	8.93578189E-08	80	7.99560547E-09	9.99999992E-01	9.99200000E-01
	2	1.00E+02	8.93284451E-08	80	9.99999992E-01	7.99541473E-09	9.99200000E-01
3 exlunit	1	0.00E+00	0.00000000E+00	80	0.00000000E+00	1.00000000E+00	9.99200000E-01
	2	8.65E+01	8.60295668E-02	25787	8.64645486E-01	1.35354514E-01	7.42130800E-01
	3	1.27E+01	8.21188465E-02	2601	1.26507016E-01	8.73492984E-01	9.73990000E-01
	4	8.85E-01	2.10576057E-02	80	8.84749857E-03	9.91152501E-01	9.99200000E-01
4 gt	1	0.00E+00	0.00000000E+00	80	0.00000000E+00	1.00000000E+00	9.99200000E-01
	2	1.00E+02	0.00000000E+00	80	1.00000000E+00	-1.90727434E-13	9.99200000E-01

PRIMITIVE NO NAME	TRANS. FR	TO	TOTAL NO OCCURNCS	NON-ZERO RUNS	MEAN TIME BETW TRNS	RELIABILITY	UNRELIABILITY
2 rp	1	2	80	80	1.25E+05	9.99200000E-01	8.00000000E-04
	2	1	80	80	1.25E+05	9.99200000E-01	8.00000000E-04
3 exlunit	1	2	80	80	1.25E+05	9.99200000E-01	8.00000000E-04
	2	3	8637	8636	1.16E+03	9.13640000E-01	8.63600000E-02
	2	3	8658	8656	1.16E+03	9.13440000E-01	8.65600000E-02
	2	3	8503	8502	1.18E+03	9.14980000E-01	8.50200000E-02
	3	4	1310	1309	7.63E+03	9.86910000E-01	1.30900000E-02
	3	4	1293	1292	7.73E+03	9.87080000E-01	1.29200000E-02
	4	1	80	80	1.25E+05	9.99200000E-01	8.00000000E-04
4 gt	1	2	80	80	1.25E+05	9.99200000E-01	8.00000000E-04
	2	1	80	80	1.25E+05	9.99200000E-01	8.00000000E-04

System Reliability

SIMULATION RESULTS

Simulation name: example1
Number of simulation runs: 10000
Single run duration: 100000.0
Number of monitored primitives: 3
Random number seed: 12345

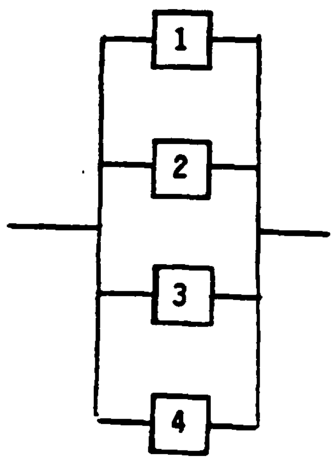
PRIMITIVE DESCR. NO NAME	TRANSITION TYPE	TRANSITION AND MODE DESCRIPTION FROM MODE(NO/NAME)	TO MODE(NO/NAME)
2 rp	delay/warmup	1 rep	2 idle
	control	2 idle	1 rep
3 exlunit	control	1 fail	2 up3
	failure	2 up3	3 up2
	failure	2 up3	3 up2
	failure	2 up3	3 up2
	failure	3 up2	4 up1
	failure	3 up2	4 up1
	failure	4 up1	1 fail
4 gt	control	1 one	2 two
	control	2 two	1 one

PRIMITIVE NO NAME	MODE NO	AVERAGE TIME	STANDARD DEVIATION	NON-0 RUNS	AVAILABILITY	UNAVAILABILITY	RELIABILITY
2 rp	1	9.79E-04	7.60112968E-08	10000	9.78601074E-09	9.99999990E-01	0.00000000E+00
	2	1.00E+05	7.65465575E-06	10000	9.99999991E-01	8.92828370E-09	0.00000000E+00
3 exlunit	1	9.82E+04	1.16647997E+01	0	9.81646266E-01	1.83537341E-02	1.00000000E+00
	2	3.34E+02	3.33509326E+00	10000	3.33731531E-03	9.96662685E-01	0.00000000E+00
	3	4.98E+02	4.91030407E+00	10000	4.98203122E-03	9.95017969E-01	0.00000000E+00
	4	1.00E+03	1.00877590E+01	10000	1.00343885E-02	9.89965612E-01	0.00000000E+00
4 gt	1	9.82E+04	1.16647997E+01	0	9.81646266E-01	1.83537341E-02	1.00000000E+00
	2	$\boxed{1.84E+03}$	1.16647997E+01	10000	1.83537349E-02	9.81646265E-01	0.00000000E+00

MTBCF

PRIMITIVE NO NAME	TRANS. FR	TO	TOTAL NO OCCURNCS	NON-ZERO RUNS	MEAN TIME BETW TRNS	RELIABILITY	UNRELIABILITY
2 rp	1	2	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00
	2	1	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00
3 exlunit	1	2	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
	2	3	3366	3366	2.97E+05	6.63400000E-01	3.36600000E-01
	2	3	3372	3372	2.97E+05	6.62800000E-01	3.37200000E-01
	2	3	3262	3262	3.07E+05	6.73800000E-01	3.26200000E-01
	3	4	5017	5017	1.99E+05	4.98300000E-01	5.01700000E-01
	3	4	4983	4983	2.01E+05	5.01700000E-01	4.98300000E-01
	4	1	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00
4 gt	1	2	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
	2	1	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00

Example 2: Simple Standby Redundancy (Deferred Repair). **Repair Philosophy – Assume that corrective repair is deferred until a critical failure occurs. Repair occurs instantaneously at that time.**



$\lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = .001$ **failures/hr**

2 out of 4 units required for success

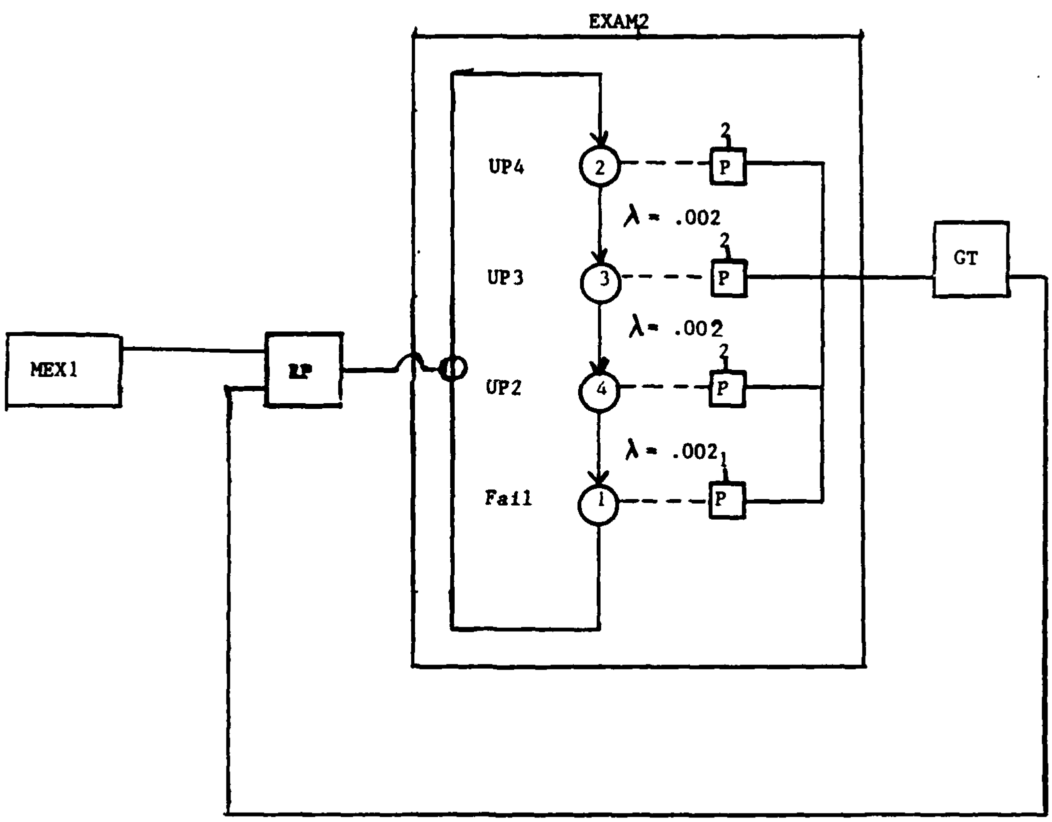
Compute:

1. MTBCF
2. Reliability at time $t = 100$ Hrs ($R(100)$)

Example 2

Example 2 is similar to example 1 except that there are 4 units and 2 out of 4 are required for acceptable operation. Also since this is standby redundancy, the units are assumed not to fail in the standby mode. Figure 2 shows the FASTER diagram which represents the system. A GT block triggers repair when the third failure occurs. To obtain the system reliability for a 100 hour mission, 100,000 runs are conducted. The resulting reliability is 0.99886. To compute MTBCF, a long mission (100,000 hours) is simulated with repair deactivated by connecting EXAM2 directly to MEX1. In this case the MTBCF is 1500 hours.

Example 2



EXAM2
UP4
2
2
P
λ = .002
2
UP3
3
P
GT
λ = .002
2
MEX1
RP
UP2
4
P
λ = .002
1
Fail
1
P

SIMULATION RESULTS

Simulation name: EXAMPLE2
Number of simulation runs: 100000
Single run duration: 100.0000
Number of monitored primitives: 3
Random number seed: 12345

PRIMITIVE DESCR. NO NAME	TRANSITION TYPE	TRANSITION AND MODE DESCRIPTION FROM MODE(NO/NAME)	TO MODE(NO/NAME)
2 rp	delay/warmup	1 rep	2 idle
	control	2 idle	1 rep
3 exam2	control	1 fail	2 up4
	failure	2 up4	3 up3
	failure	3 up3	4 up2
	failure	4 up2	1 fail
4 gt	control	1 one	2 two
	control	2 two	1 one

PRIMITIVE NO NAME	MODE NO	AVERAGE TIME	STANDARD DEVIATION	NON-0 RUNS	AVAILABILITY	UNAVAILABILITY	RELIABILITY
2 rp	1	1.14E-06	1.06652180E-07	114	1.13938332E-08	9.99999989E-01	9.98860000E-01
	2	1.00E+02	1.06614287E-07	114	9.99999989E-01	1.13936424E-08	9.98860000E-01
3 exam2	1	2.94E-02	3.46837402E-03	0	2.94273662E-04	9.99705726E-01	1.00000000E+00
	2	9.07E+01	7.36323521E-02	18174	9.06682961E-01	9.33170390E-02	8.18260000E-01
	3	8.71E+00	7.01216087E-02	1798	8.71436212E-02	9.12856379E-01	9.82020000E-01
	4	5.88E-01	1.69653557E-02	114	5.87914467E-03	9.94120855E-01	9.98860000E-01
4 gt	1	2.94E-02	3.46837402E-03	0	2.94273662E-04	9.99705726E-01	1.00000000E+00
	2	1.00E+02	3.46837402E-03	114	9.99705726E-01	2.94273662E-04	9.98860000E-01

PRIMITIVE NO NAME	TRANS. FR	TO	TOTAL NO OCCURNCS	NON-ZERO RUNS	MEAN TIME BETW TRNS	RELIABILITY	UNRELIABILITY
2 rp	1	2	114	114	8.77E+04	9.98860000E-01	1.14000000E-03
	2	1	114	114	8.77E+04	9.98860000E-01	1.14000000E-03
3 exam2	1	2	0	0	1.00E+02	1.00000000E+00	0.00000000E+00
	2	3	18174	18174	5.50E+02	8.18260000E-01	1.81740000E-01
	3	4	1798	1798	5.56E+03	9.82020000E-01	1.79800000E-02
	4	1	114	114	8.77E+04	9.98860000E-01	1.14000000E-03
4 gt	1	2	0	0	1.00E+02	1.00000000E+00	0.00000000E+00
	2	1	114	114	8.77E+04	9.98860000E-01	1.14000000E-03

System Reliability

SIMULATION RESULTS

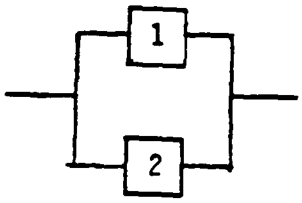
Simulation name: example2
Number of simulation runs: 10000
Single run duration: 100000.0
Number of monitored primitives: 3
Random number seed: 12345

PRIMITIVE DESCR. NO NAME	TRANSITION TYPE	TRANSITION AND MODE DESCRIPTION FROM MODE(NO/NAME)	TO MODE(NO/NAME)
2 rp	delay/warmup	1 rep	2 idle
	control	2 idle	1 rep
3 exam2	control	1 fail	2 up4
	failure	2 up4	3 up3
	failure	3 up3	4 up2
	failure	4 up2	1 fail
4 gt	control	1 one	2 two
	control	2 two	1 one

PRIMITIVE NO NAME	MODE NO	AVERAGE TIME	STANDARD DEVIATION	NON-0 RUNS	AVAILABILITY	UNAVAILABILITY	RELIABILITY
2 rp	1	9.79E-04	8.34740206E-08	10000	9.79061890E-09	9.99999990E-01	0.00000000E+00
	2	1.00E+05	1.39754247E-05	10000	9.99999991E-01	9.26424789E-09	0.00000000E+00
3 exam2	1	9.85E+04	8.51502609E+00	0	9.85035275E-01	1.49647246E-02	1.00000000E+00
	2	4.96E+02	4.95649910E+00	10000	4.96385312E-03	9.95036147E-01	0.00000000E+00
	3	4.99E+02	4.96601486E+00	10000	4.98623240E-03	9.95013768E-01	0.00000000E+00
	4	5.01E+02	4.94715977E+00	10000	5.01463990E-03	9.94985360E-01	0.00000000E+00
4 gt	1	9.85E+04	8.51502609E+00	0	9.85035275E-01	1.49647246E-02	1.00000000E+00
	2	$\boxed{1.50E+03}$ MTBCF	8.51502609E+00	10000	1.49647253E-02	9.85035275E-01	0.00000000E+00

PRIMITIVE NO NAME	TRANS. FR	TO	TOTAL NO OCCURNCS	NON-ZERO RUNS	MEAN TIME BETW TRNS	RELIABILITY	UNRELIABILITY
2 rp	1	2	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00
	2	1	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00
3 exam2	1	2	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
	2	3	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00
	3	4	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00
	4	1	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00
4 gt	1	2	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
	2	1	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00

Example 3: Simple Active Redundancy (Immediate Repair). Repair Philosophy – Immediate concurrent repair is assumed. A maintenance crew is available to immediately repair any failed resources no matter how many fail during the same time period. Repair is performed while the remaining operating unit supports the operational function.



$\lambda_1 = \lambda_2 = .001$ failures/hr

$\mu_1 = \mu_2 = .05$ repairs/hr

1 out of 2 units required for success

Compute:

1. MTBCF
2. System Mean-Time-To-Repair (MTTR)
3. Steady State Availability

Example 3

Example 3 is a system for which repair begins immediately when a unit failure occurs. A non-constant repair time is used. The repair process has an MTTR of 0.05 repairs/hour which is implemented using a failure transition rate equal to 0.05. Each subsystem has an MTBF of 1000 hours. The LIB_OR defines the overall system operation and the LIB_TIMER keeps track of the up time to compute availability.

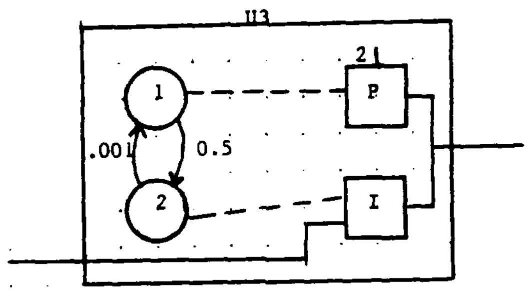
The first run was for a 100,000 hour mission. Results show the system availability of 0.99962 and an MTBCF of 26,400 hours. To compute the MTTR of the system, three numbers from the FASTER output are used. These are: the number of runs (N = 5000), total number of failures (NF = 18948), and the average time under repair (TR = 37.6 hours). Note that NF is obtained by the number of mode 2 to mode 1 transitons of LIB_TIMER block 5 and TR is the average time LIB_TIMER spends in mode 1.

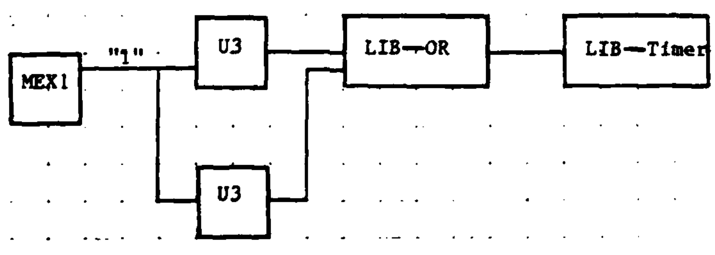
The MTTR is given by:

$$\text{MTTR} = \text{TR}/(\text{NF}/\text{NR})$$

The resulting value is 9.9 hours.

EXAMPLE 3.





SIMULATION RESULTS

Simulation name: ex3
Number of simulation runs: 5000
Single run duration: 100000.0
Number of monitored primitives: 4
Random number seed: 12345

PRIMITIVE DESCR. NO NAME	TRANSITION TYPE	TRANSITION AND MODE DESCRIPTION FROM MODE(NO/NAME)	TO MODE(NO/NAME)
2 u3	failure	1 up	2 failed
	failure	2 failed	1 up
3 u3	failure	1 up	2 failed
	failure	2 failed	1 up
5 lib_timer	control	1 down	2 up
	control	2 up	1 down

PRIMITIVE NO NAME	MODE NO	AVERAGE TIME	STANDARD DEVIATION	NON-0 RUNS	AVAILABILITY	UNAVAILABILITY	RELIABILITY
2 u3	1	9.80E+04	3.81163192E+00	5000	9.80456117E-01	1.95438835E-02	0.00000000E+00
	2	1.95E+03	3.81163192E+00	5000	1.95438837E-02	9.80456116E-01	0.00000000E+00
3 u3	1	9.80E+04	3.88957000E+00	5000	9.80403903E-01	1.95960969E-02	0.00000000E+00
	2	1.96E+03	3.88957000E+00	5000	1.95960971E-02	9.80403903E-01	0.00000000E+00
5 lib_timer	1	$\boxed{3.76E+01}$	3.87400538E-01	4883	3.76388653E-04	9.99623611E-01	2.34000000E-02
	2	1.00E+05	3.87400597E-01	4883	$\boxed{9.99623615E-01}$	3.76385404E-04	2.34000000E-02

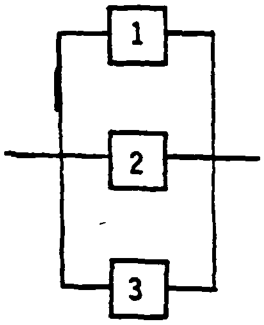
Average time under repair   Availability

PRIMITIVE NO NAME	TRANS. FR	TO	TOTAL NO OCCURNCS	NON-ZERO RUNS	MEAN TIME BETW TRNS	RELIABILITY	UNRELIABILITY
2 u3	1	2	489012	5000	1.02E+03	0.00000000E+00	1.00000000E+00
	2	1	488905	5000	1.02E+03	0.00000000E+00	1.00000000E+00
3 u3	1	2	490049	5000	1.02E+03	0.00000000E+00	1.00000000E+00
	2	1	489942	5000	1.02E+03	0.00000000E+00	1.00000000E+00
5 lib_timer	1	2	18947	4883	2.64E+04	2.34000000E-02	9.76600000E-01
	2	1	$\boxed{18948}$	4883	$\boxed{2.64E+04}$	2.34000000E-02	9.76600000E-01

3.79 events/run   MTBCF

MTTR = 37.6/3.71 = 9.92

Example 4: Simple Active Redundancy (Scheduled Preventive Maintenance). Repair Philosophy Assume that corrective repair is deferred until a critical failure occurs, repair occurs instantaneously at that time, however scheduled preventive maintenance is conducted at regular time intervals. During each scheduled maintenance action each unit of the system is repaired, while the remaining operating units carry on the system function. T_p denotes the *scheduled maintenance interval*. Every T_p hours the system is replenished, i.e. all failed units are repaired and put back on line.



$\lambda_1 = \lambda_2 = \lambda_3 = .005$ failures/hr

$T_p = 100$ Hrs

1 out of 3 units required for mission success

Computer:

1. MTBCF

2. Reliability at time t 200 Hr

Example 4

The FASTER diagram for example 4 includes a mission block which normally outputs a 2 but outputs a 1 every 100 hours to cause a failure reset of any failed U4 units. To set up the mission block to output a 1 every 100 hours, the mission editor is used to enter the data in the table which is on the figure for example 4. Details on how to use the mission editor are in the user's guide. The GT block also outputs a 1 if all three U4 units fail. This causes all three U4 units to reset.

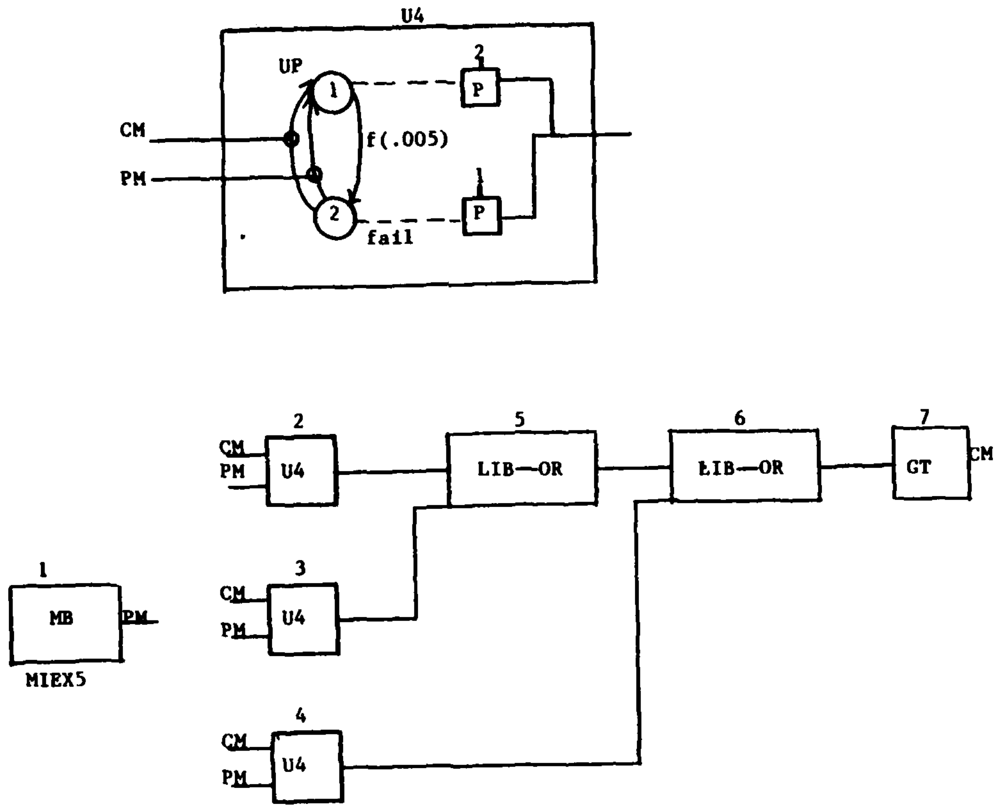
To run the simulation, a mission time of 200 hours was used because reliability at 200 hours is desired.

The resulting system reliability is 0.8778 which is obtained from block GT-7. Also, the MBTCF of the system is 1590 hours. The results also show that the number of total critical failures in all 10,000 missions was 1257 and that the number of preventative maintenance repairs for one U4 subsystem is about 6684. This shows that preventative maintenance greatly increases the system reliability and MTBCF.

Note that in this example, the MTBCF is computed using a short run equal to the mission length. This is possible because the system is reset every 100 hours. As long as the mission time is a multiple of 100 hours, this approach is valid.

In contrast, the other examples require a long simulation to compute MTBCF values. This is because the critical failure rate is time dependent due to the changes in the system. In example 6, as more individual primitives fail, the critical failure rate increases. Thus the critical failure rate at $t = 0$ is lower than the critical failure rate at $t = 720$ hours because the system is likely to have some failed subunits at $t = 720$ hours. If the approach used in example 4 were used in example 6, a longer (and wrong) MTBCF would be obtained.

Example 4



Mission Block = MB

T	V
0	2
99	1
100	2
199	1
200	2
299	1
300	2
399	1
400	2
499	1
500	2

SIMULATION RESULTS

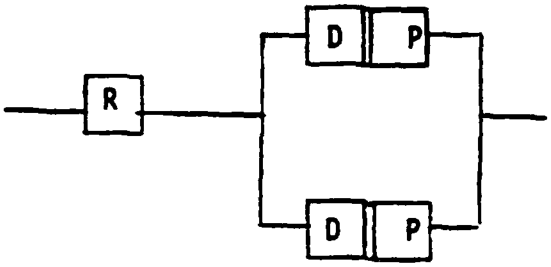
Simulation name: EX4
Number of simulation runs: 10000
Single run duration: 200.0000
Number of monitored primitives: 6
Random number seed: 12345

PRIMITIVE DESCR. NO NAME	TRANSITION TYPE	TRANSITION AND MODE DESCRIPTION FROM MODE(NO/NAME)	TO MODE(NO/NAME)
2 u4	failure	1 up	2 fail
	control	2 fail	1 up
	control	2 fail	1 up
3 u4	failure	1 up	2 fail
	control	2 fail	1 up
	control	2 fail	1 up
4 u4	failure	1 up	2 fail
	control	2 fail	1 up
	control	2 fail	1 up
7 gt	control	1 one	2 two
	control	2 two	1 one

PRIMITIVE NO NAME	MODE NO	AVERAGE TIME	STANDARD DEVIATION	NON-0 RUNS	AVAILABILITY	UNAVAILABILITY	RELIABILITY
2 u4	1	1.58E+02	4.50550795E-01	6371	7.87630938E-01	2.12369062E-01	3.62900000E-01
	2	4.25E+01	4.50550795E-01	6356	2.12369063E-01	7.87630937E-01	3.64400000E-01
3 u4	1	1.58E+02	4.49388921E-01	6353	7.88005823E-01	2.11994177E-01	3.64700000E-01
	2	4.24E+01	4.49388921E-01	6325	2.11994177E-01	7.88005823E-01	3.67500000E-01
4 u4	1	1.58E+02	4.46528822E-01	6291	7.92257954E-01	2.07742046E-01	3.70900000E-01
	2	4.15E+01	4.46528822E-01	6273	2.07742047E-01	7.92257953E-01	3.72700000E-01
7 gt	1	3.68E+00	1.24573581E-01	1224	1.84188625E-02	9.81581138E-01	8.77600000E-01
	2	1.96E+02	1.24573581E-01	1224	9.81581138E-01	1.84188625E-02	8.77600000E-01

PRIMITIVE NO NAME	TRANS. FR	TO	TOTAL NO OCCURNCS	NON-ZERO RUNS	MEAN TIME BETW TRNS	RELIABILITY	UNRELIABILITY
2 u4	1	2	7937	6371	2.52E+02	3.62900000E-01	6.37100000E-01
	2	1	0	0	2.00E+02	1.00000000E+00	0.00000000E+00
	2	1	7886	6356	2.54E+02	3.64400000E-01	6.35600000E-01
3 u4	1	2	7930	6353	2.52E+02	3.64700000E-01	6.35300000E-01
	2	1	0	0	2.00E+02	1.00000000E+00	0.00000000E+00
	2	1	7874	6325	2.54E+02	3.67500000E-01	6.32500000E-01
4 u4	1	2	7759	6291	2.58E+02	3.70900000E-01	6.29100000E-01
	2	1	0	0	2.00E+02	1.00000000E+00	0.00000000E+00
	2	1	7710	6273	2.59E+02	3.72700000E-01	6.27300000E-01
7 gt	1	2	1262	1224	1.58E+03	8.77600000E-01	1.22400000E-01
	2	1	1262	1224	1.58E+03	8.77600000E-01	1.22400000E-01
					MTBCF	System Reliability	

Example 5: Active Redundancy (with Imperfect Diagnostics and Switching), upon the occurrence of a failure, the faulty unit is switched off. Repair Philosophy - Assume that manual corrective repair is deferred until a critical failure occurs.



R - Recovery/switching Unit

D - Diagnostics Unit

P - Prime Unit

1 out of 2 units required for mission success

Assumptions:

- Recovery unit failure does not immediately cause system failure but, next prime failure after a recovery unit failure will cause system failure.
- Failure to switch off a failed unit will cause a system failure.
- Diagnostics unit failure does not immediately cause system failure then a system failure will occur (because the failed unit will not be able to be switched off).
- Undetected prime unit failure causes system failure.
- Diagnositics units are inactivated when the associated prime unit is switched off.

λ_R = .0002 failures/hr

λ_D = .0002 failures/hr

λ_p = .001 failures/hr

Fraction of Faults Detectable (FFD) 1.00

Compute:

1. MTBCF

2. Reliability at time t = 1000 hr

Example 5

Example 5-FASTER Diagram.

The following figures show a FASTER diagram for example 5. The diagnositics unit detects all failures when there is no failure of the diagnostics unit. The primary unit has four modes. The diagram for the primary unit (PUNIT) shows these modes. Under each mode are three parameter blocks which drive the outputs of PUNIT with the indicated value. The failure detect line (D) becomes a "2" just after a failure. If the PUNIT is switched off (mode 4) by driving C4 with a "4", then a unit failure occurs. However, if the unit is not switched of (before T=.001), then a system failure occurs (mode 3). By using "ANDS" and "OR" (see top level example 5 diagram), a critical failure is defined as 1) both units fail or 2) at least one unit fails and is not switched off.

The primitive DUNIT detects failures and causes the R block to switch off the PUNIT. If DUNIT fails, then it will not detect the failure. Also if the R unit fails, switching will not occur. The block GT was shown in previous examples. GT is a timer which keeps track of which mode the system is in.

If imperfect failure detection occurs (FFD = 0.9 for example) then the PUNIT block could be modified so that 10% of the time the "2" on output number 3 is set to "1". A "PROB" subprimitive could be used to do this.

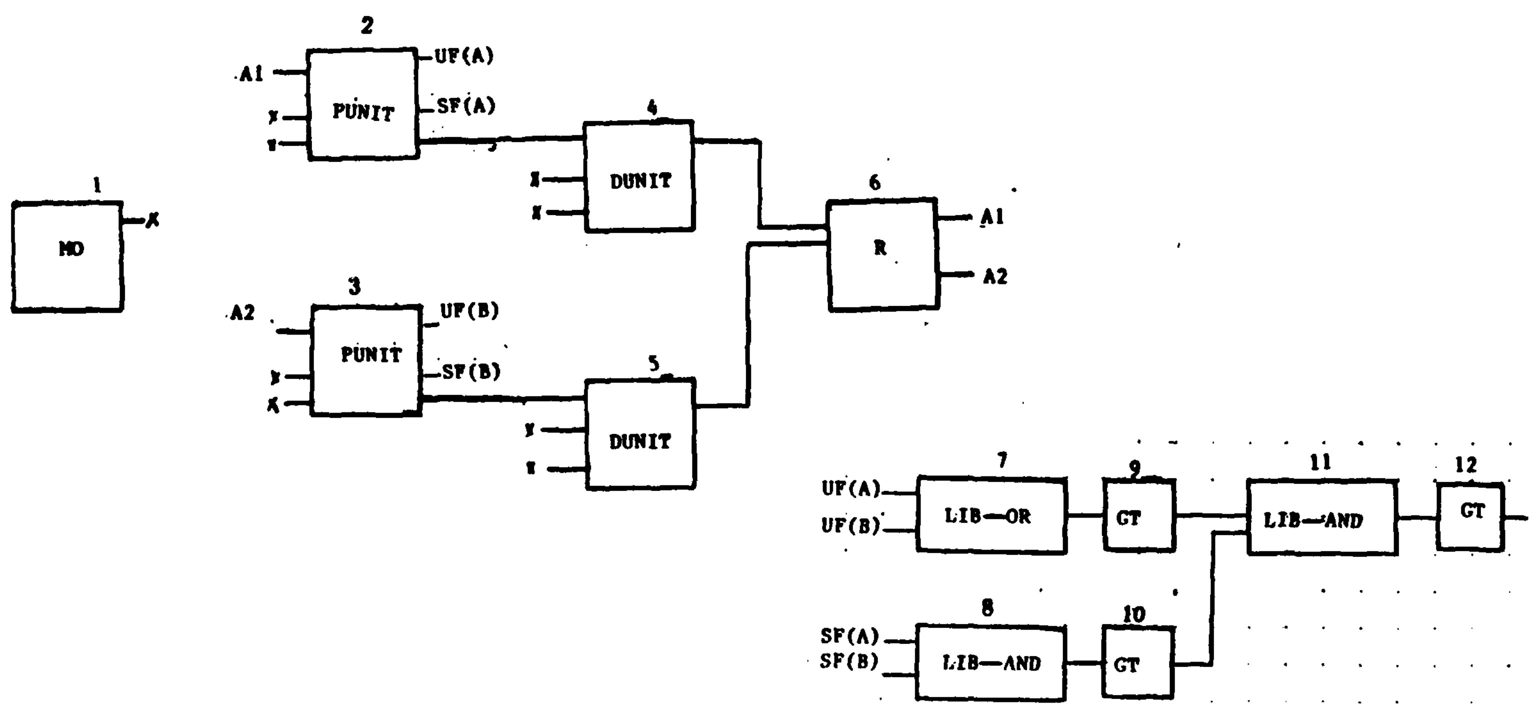
Example 5 Results:

Three runs were made for example 5. The first run was set up to obtain reliability for a 1000 hour mission. Repair was disabled so that the number fo critical failures in 10,000 missions could be obtained. The number of mode 2 to mode 1 transitions gives this number (4746). The overall system reliability is then given by (10,000 - 4746)/10,000 = 0.525.

A second run (with repair disabled) was conducted to obtain MBTCF. A long mission was specified to insure that a critical failure occurs for each run. The MBTCF is then given by the average time the block GT-12 stays in mode 2 (1340 hours).

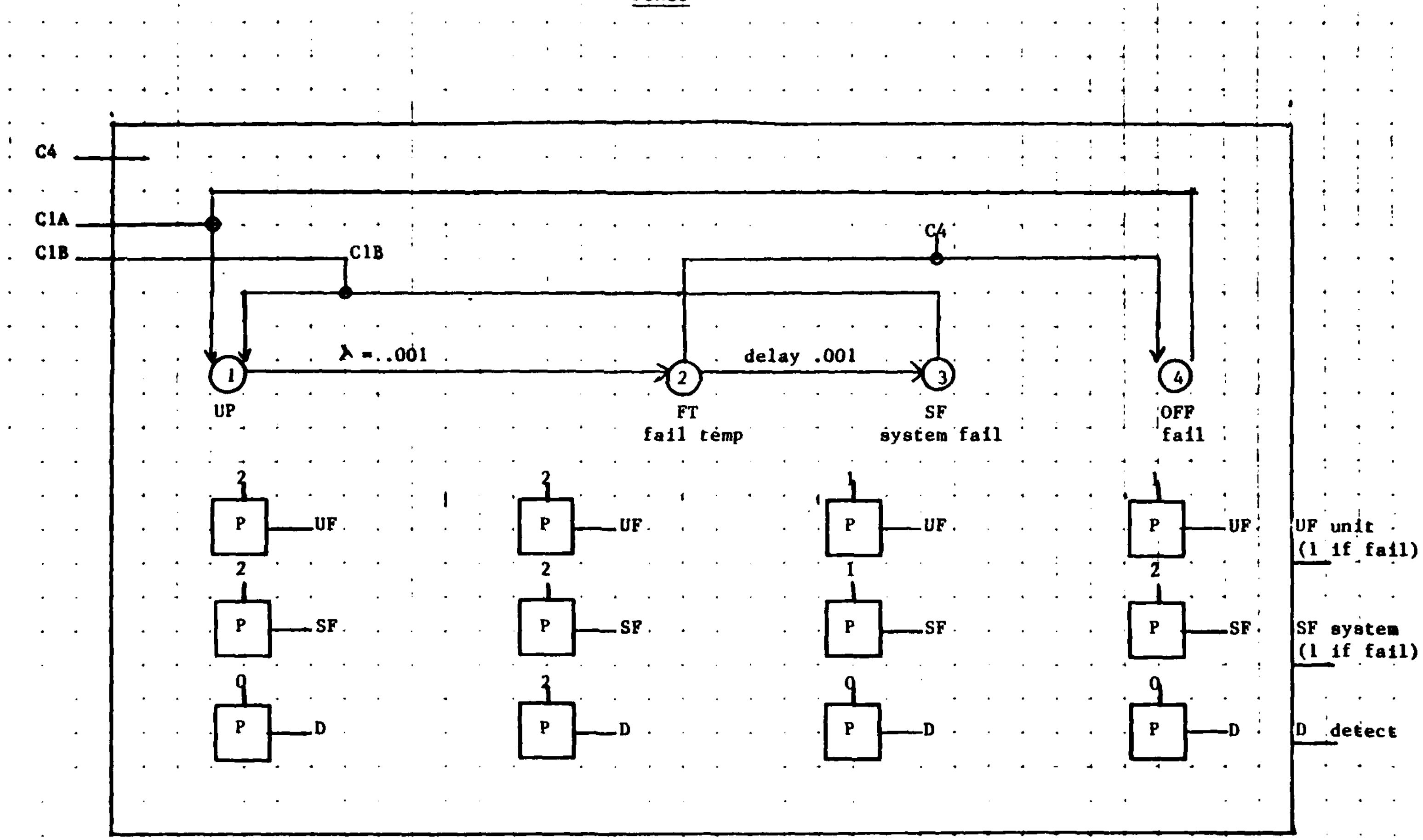
A third run was made to obtain the MBTCF for an ultra reliable recovery unit. The failure rate of the R unit was changed from 0.2 X 10^{-8}. The resulting system MBTCF is 1410 hours.

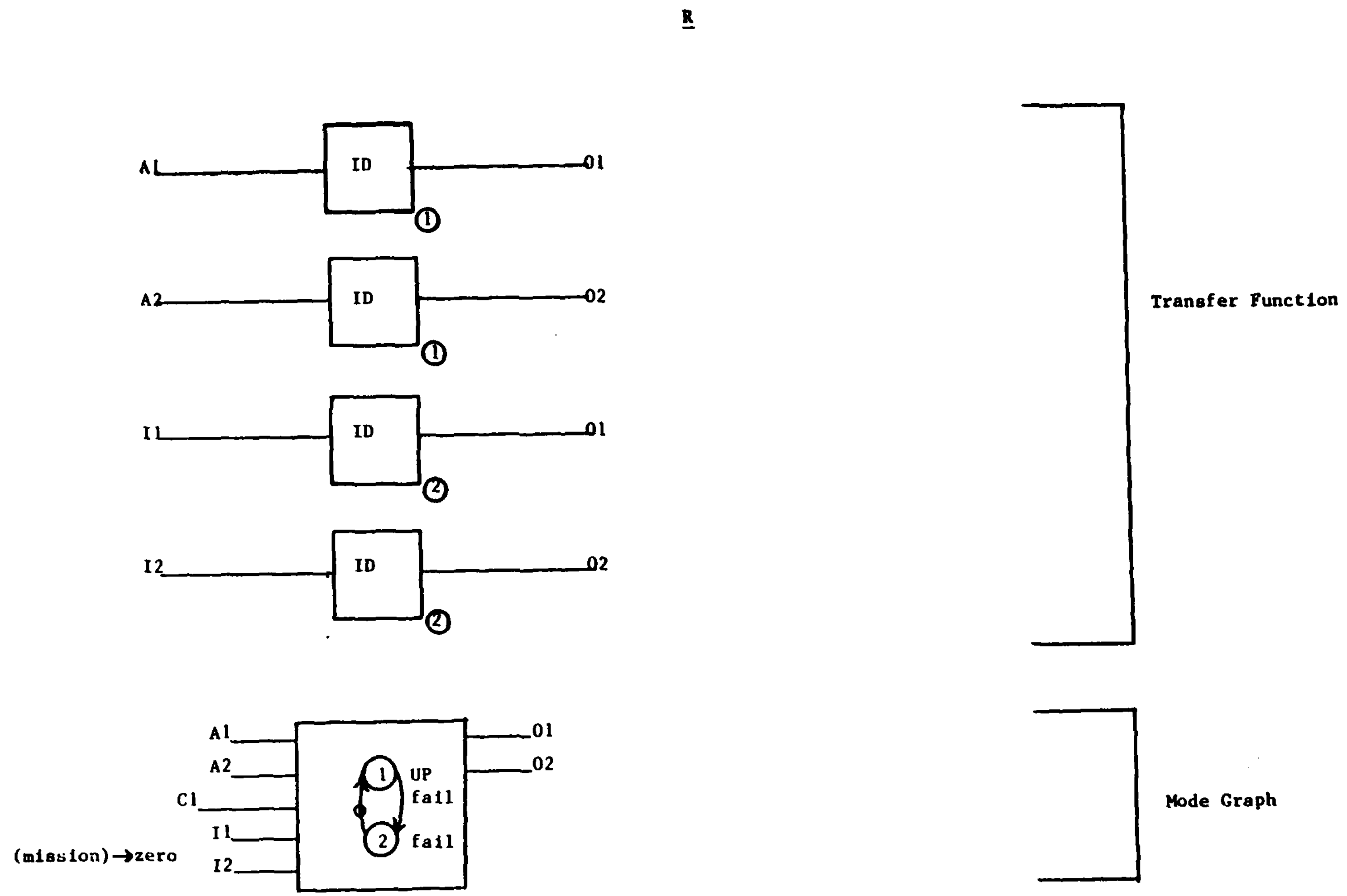
<u>EXAMPLE 5</u>



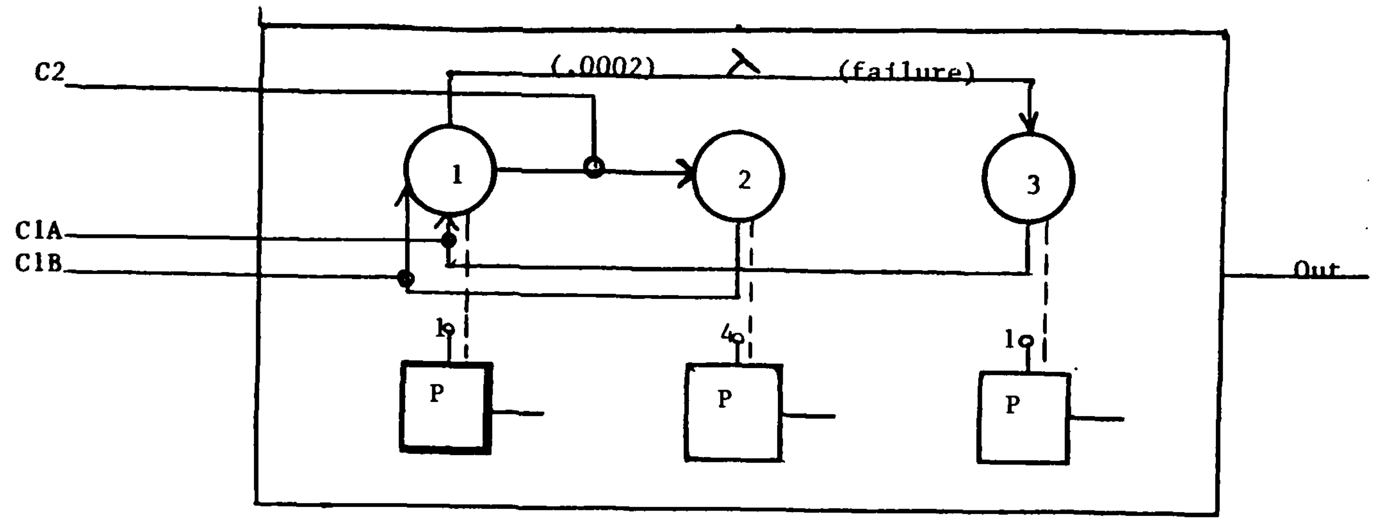
1
MO
2
PUNIT
A1
UF(A)
SF(A)
3
PUNIT
A2
UF(B)
SF(B)
4
DUNIT
5
DUNIT
6
R
A1
A2
7
LIB—OR
UF(A)
UF(B)
8
LIB—AND
SF(A)
SF(B)
9
GT
10
GT
11
LIB—AND
12
GT

PUNIT


C4
C1A
C1B
C1B
C4
λ = .001
delay .001
1
UP
2
FT
fail temp
3
SF
system fail
4
OFF
fail
2
P
UF
2
P
SF
0
P
D
2
P
UF
2
P
SF
2
P
D
1
P
UF
1
P
SF
0
P
D
1
P
UF
2
P
SF
0
P
D
UF unit
(1 if fail)
SF system
(1 if fail)
D detect


R
A1
ID
01
1
A2
ID
02
1
I1
ID
01
2
I2
ID
02
2
Transfer Function
A1
A2
C1
I1
I2
(mission)→zero
1
UP
fail
2
fail
01
02
Mode Graph

DUNIT



Run 1

Run 1 was done to obtain the system reliability. A 1,000 hour mission was selected.

SIMULATION RESULTS

Simulation name: exa5
Number of simulation runs: 10000
Single run duration: 1000.000
Number of monitored primitives: 11
Random number seed: 12345

PRIMITIVE DESCR. NO NAME	TRANSITION TYPE	TRANSITION AND MODE DESCRIPTION FROM MODE(NO/NAME)	TO MODE(NO/NAME)
2 punit	failure	1 up	2 ft
	control	2 ft	4 off
	delay/warmup	2 ft	3 sf
	control	3 sf	1 up
	control	4 off	1 up
3 punit	failure	1 up	2 ft
	control	2 ft	4 off
	delay/warmup	2 ft	3 sf
	control	3 sf	1 up
	control	4 off	1 up
4 dunit	control	1 up	2 fdet
	failure	1 up	3 fail
	control	2 fdet	1 up
	control	3 fail	1 up
5 dunit	control	1 up	2 fdet
	failure	1 up	3 fail
	control	2 fdet	1 up
	control	3 fail	1 up
6 r	failure	1 up	2 fail
	control	2 fail	1 up
8 gt	control	1 one	2 two
	control	2 two	1 one
10 gt	control	1 one	2 two
	control	2 two	1 one
12 gt	control	1 one	2 two
	control	2 two	1 one

PRIMITIVE NO NAME	MODE NO	AVERAGE TIME	STANDARD DEVIATION	NON-0 RUNS	AVAILABILITY	UNAVAILABILITY	RELIABILITY
2 punit	1	6.36E+02	3.58738995E+00	6308	6.36208140E-01	3.63791860E-01	3.69200000E-01
	2	9.42E-05	2.89962009E-06	6308	9.41535950E-08	9.99999906E-01	3.69200000E-01
	3	3.69E+01	1.38029146E+00	0	3.68888544E-02	9.63111146E-01	1.00000000E+00
	4	3.27E+02	3.65731788E+00	0	3.26902915E-01	6.73097085E-01	1.00000000E+00
3 punit	1	6.27E+02	3.60348439E+00	6394	6.26674542E-01	3.73325458E-01	3.60600000E-01
	2	9.49E-05	2.91039737E-06	6394	9.49409485E-08	9.99999905E-01	3.60600000E-01
	3	3.79E+01	1.39009416E+00	0	3.78873992E-02	9.62112601E-01	1.00000000E+00
	4	3.35E+02	3.68707347E+00	0	3.35437967E-01	6.64562033E-01	1.00000000E+00
4 dunit	1	5.86E+02	3.59892845E+00	6949	5.86336230E-01	4.13663770E-01	3.05100000E-01
	2	3.44E+02	3.62784052E+00	0	3.43743908E-01	6.56256092E-01	1.00000000E+00
	3	6.99E+01	2.14428687E+00	0	6.99198658E-02	9.30080134E-01	1.00000000E+00
5 dunit	1	5.79E+02	3.60767412E+00	7012	5.79118022E-01	4.20881978E-01	2.98800000E-01
	2	3.53E+02	3.65302300E+00	0	3.52828330E-01	6.47171670E-01	1.00000000E+00
	3	6.81E+01	2.11494350E+00	0	6.80536520E-02	9.31946348E-01	1.00000000E+00
6 r	1	9.09E+02	2.29787922E+00	1797	9.08509903E-01	9.14900973E-02	8.20300000E-01

	2	9.15E+01	2.29787946E+00	0	9.14900982E-02	9.08509902E-01	1.00000000E+00
9 gt	1	1.67E+02	2.60326648E+00	0	1.67131169E-01	8.32868831E-01	1.00000000E+00
	2	8.33E+02	2.60326648E+00	4044	8.32868833E-01	1.67131167E-01	5.95600000E-01
10 gt	1	6.85E+01	1.84053576E+00	0	6.84913628E-02	9.31508637E-01	1.00000000E+00
	2	9.32E+02	1.84053576E+00	1681	9.31508638E-01	6.84913621E-02	8.31900000E-01
12 gt	1	2.06E+02	2.80305839E+00	0	2.06450975E-01	7.93549025E-01	1.00000000E+00
	2	7.94E+02	2.80305839E+00	4746	7.93549027E-01	2.06450973E-01	5.25400000E-01

PRIMITIVE NO NAME	TRANS. FR	TO	TOTAL NO OCCURNCS	NON-ZERO RUNS	MEAN TIME BETW TRNS	RELIABILITY	UNRELIABILITY
2 punit	1	2	6308	6308	1.59E+03	3.69200000E-01	6.30800000E-01
	2	4	5354	5354	1.07E+03	4.64600000E-01	5.35400000E-01
	2	3	954	954	1.05E+04	9.04600000E-01	9.54000000E-02
	3	1	0	0	1.00E+03	1.00000000E+00	0.00000000E+00
	4	1	0	0	1.00E+03	1.00000000E+00	0.00000000E+00
3 punit	1	2	6394	6394	1.56E+03	3.60600000E-01	6.39400000E-01
	2	4	5432	5432	1.84E+03	4.56800000E-01	5.43200000E-01
	2	3	962	962	1.04E+04	9.03800000E-01	9.62000000E-02
	3	1	0	0	1.00E+03	1.00000000E+00	0.00000000E+00
	4	1	0	0	1.00E+03	1.00000000E+00	0.00000000E+00
4 dunit	1	2	5798	5798	1.72E+03	4.20200000E-01	5.79800000E-01
	1	3	1151	1151	8.69E+03	8.84900000E-01	1.15100000E-01
	2	1	0	0	1.00E+03	1.00000000E+00	0.00000000E+00
	3	1	0	0	1.00E+03	1.00000000E+00	0.00000000E+00
5 dunit	1	2	5874	5874	1.70E+03	4.12600000E-01	5.87400000E-01
	1	3	1138	1138	8.79E+03	8.86200000E-01	1.13800000E-01
	2	1	0	0	1.00E+03	1.00000000E+00	0.00000000E+00
	3	1	0	0	1.00E+03	1.00000000E+00	0.00000000E+00
6 r	1	2	1797	1797	5.56E+03	8.20300000E-01	1.79700000E-01
	2	1	0	0	1.00E+03	1.00000000E+00	0.00000000E+00
9 gt	1	2	0	0	1.00E+03	1.00000000E+00	0.00000000E+00
	2	1	4044	4044	2.47E+03	5.95600000E-01	4.04400000E-01
10 gt	1	2	0	0	1.00E+03	1.00000000E+00	0.00000000E+00
	2	1	1681	1681	5.95E+03	8.31900000E-01	1.68100000E-01
12 gt	1	2	0	0	1.00E+03	1.00000000E+00	0.00000000E+00
	2	1	$\boxed{4746}$	4746	2.11E+03	5.25400000E-01	4.74600000E-01

Run 2

Run 2 obtains the system MBTCF. A long mission (100,000 hours) was specified.

SIMULATION RESULTS

Simulation name: exa5
Number of simulation runs: 10000
Single run duration: 100000.0
Number of monitored primitives: 11
Random number seed: 12345

PRIMITIVE DESCR. NO NAME	TRANSITION TYPE	TRANSITION AND MODE DESCRIPTION FROM MODE(NO/NAME)	TO MODE(NO/NAME)
2 punit	failure	1 up	2 ft
	control	2 ft	4 off
	delay/warmup	2 ft	3 sf
	control	3 sf	1 up
	control	4 off	1 up
3 punit	failure	1 up	2 ft
	control	2 ft	4 off
	delay/warmup	2 ft	3 sf
	control	3 sf	1 up
	control	4 off	1 up
4 dunit	control	1 up	2 fdet
	failure	1 up	3 fail
	control	2 fdet	1 up
	control	3 fail	1 up
5 dunit	control	1 up	2 fdet
	failure	1 up	3 fail
	control	2 fdet	1 up
	control	3 fail	1 up
6 r	failure	1 up	2 fail
	control	2 fail	1 up
9 gt	control	1 one	2 two
	control	2 two	1 one
10 gt	control	1 one	2 two
	control	2 two	1 one
12 gt	control	1 one	2 two
	control	2 two	1 one

PRIMITIVE NO NAME	MODE NO	AVERAGE TIME	STANDARD DEVIATION	NON-0 RUNS	AVAILABILITY	UNAVAILABILITY	RELIABILITY
2 punit	1	1.01E+03	1.01953926E+01	10000	1.01224308E-02	9.89877561E-01	0.00000000E+00
	2	2.81E-04	4.43257341E-06	10000	2.81067657E-09	9.99999997E-01	0.00000000E+00
	3	2.82E+04	4.44427338E+02	0	2.81795783E-01	7.18204217E-01	1.00000000E+00
	4	7.08E+04	4.49062561E+02	0	7.08081776E-01	2.91918224E-01	1.00000000E+00
3 punit	1	9.91E+02	1.00548334E+01	10000	9.90854750E-03	9.90091452E-01	0.00000000E+00
	2	2.75E-04	4.40386157E-06	10000	2.75019073E-09	9.99999997E-01	0.00000000E+00
	3	2.76E+04	4.41649750E+02	0	2.75796041E-01	7.24203959E-01	1.00000000E+00
	4	7.14E+04	4.46146057E+02	0	7.14295409E-01	2.85704591E-01	1.00000000E+00
4 dunit	1	8.43E+02	8.48742390E+00	10000	8.43066359E-03	9.91569336E-01	0.00000000E+00
	2	8.25E+04	3.70711914E+02	0	8.25096801E-01	1.74903199E-01	1.00000000E+00
	3	1.66E+04	3.70616577E+02	0	1.66472535E-01	8.33527465E-01	1.00000000E+00
5 dunit	1	8.31E+02	8.47834969E+00	10000	8.31386325E-03	9.91686137E-01	0.00000000E+00
	2	8.28E+04	3.68277252E+02	0	8.27984447E-01	1.72015553E-01	1.00000000E+00
	3	1.64E+04	3.68142181E+02	0	1.63701690E-01	8.36298310E-01	1.00000000E+00
6 r	1	4.93E+03	4.90875511E+01	10000	4.93478192E-02	9.50652181E-01	0.00000000E+00

	2	9.51E+04	4.90875473E+01	0	9.50652184E-01	4.93478163E-02	1.00000000E+00
9 gt	1	9.85E+04	1.13733826E+01	0	9.84926270E-01	1.50737297E-02	1.00000000E+00
	2	1.51E+03	1.13733835E+01	10000	1.50737300E-02	9.84926270E-01	0.00000000E+00
10 gt	1	4.42E+04	4.89325287E+02	0	4.41832528E-01	5.58167472E-01	1.00000000E+00
	2	5.58E+04	4.89325287E+02	4492	5.58167473E-01	4.41832527E-01	5.50800000E-01
12 gt	1	9.87E+04	1.06905880E+01	0	9.86577931E-01	1.34220695E-02	1.00000000E+00
	2	$\boxed{1.34E+03}$	1.06905890E+01	10000	1.34220699E-02	9.86577930E-01	0.00000000E+00

PRIMITIVE NO NAME	TRANS. FR	TO	TOTAL NO OCCURNCS	NON-ZERO RUNS	MEAN TIME BETW TRNS	RELIABILITY	UNRELIABILITY
2 punit	1	2	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00
	2	4	7132	7132	1.40E+05	2.86800000E-01	7.13200000E-01
	2	3	2868	2868	3.49E+05	7.13200000E-01	2.86800000E-01
	3	1	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
	4	1	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
3 punit	1	2	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00
	2	4	7194	7194	1.39E+05	2.80600000E-01	7.19400000E-01
	2	3	2806	2806	3.56E+05	7.19400000E-01	2.80600000E-01
	3	1	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
	4	1	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
4 dunit	1	2	8321	8321	1.20E+05	1.67900000E-01	8.32100000E-01
	1	3	1679	1679	5.96E+05	8.32100000E-01	1.67900000E-01
	2	1	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
	3	1	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
5 dunit	1	2	8349	8349	1.20E+05	1.65100000E-01	8.34900000E-01
	1	3	1651	1651	6.06E+05	8.34900000E-01	1.65100000E-01
	2	1	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
	3	1	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
6 r	1	2	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00
	2	1	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
9 gt	1	2	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
	2	1	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00
10 gt	1	2	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
	2	1	4492	4492	2.23E+05	5.50800000E-01	4.49200000E-01
12 gt	1	2	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
	2	1	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00

Run 3

Run 3 was a modified system which had a highly reliable "R" unit. The resulting MBTCF was higher because there were less system failures caused by the failure to switch out detected failures.

SIMULATION RESULTS

Simulation name: exa5
Number of simulation runs: 10000
Single run duration: 100000.0
Number of monitored primitives: 11
Random number seed: 12345

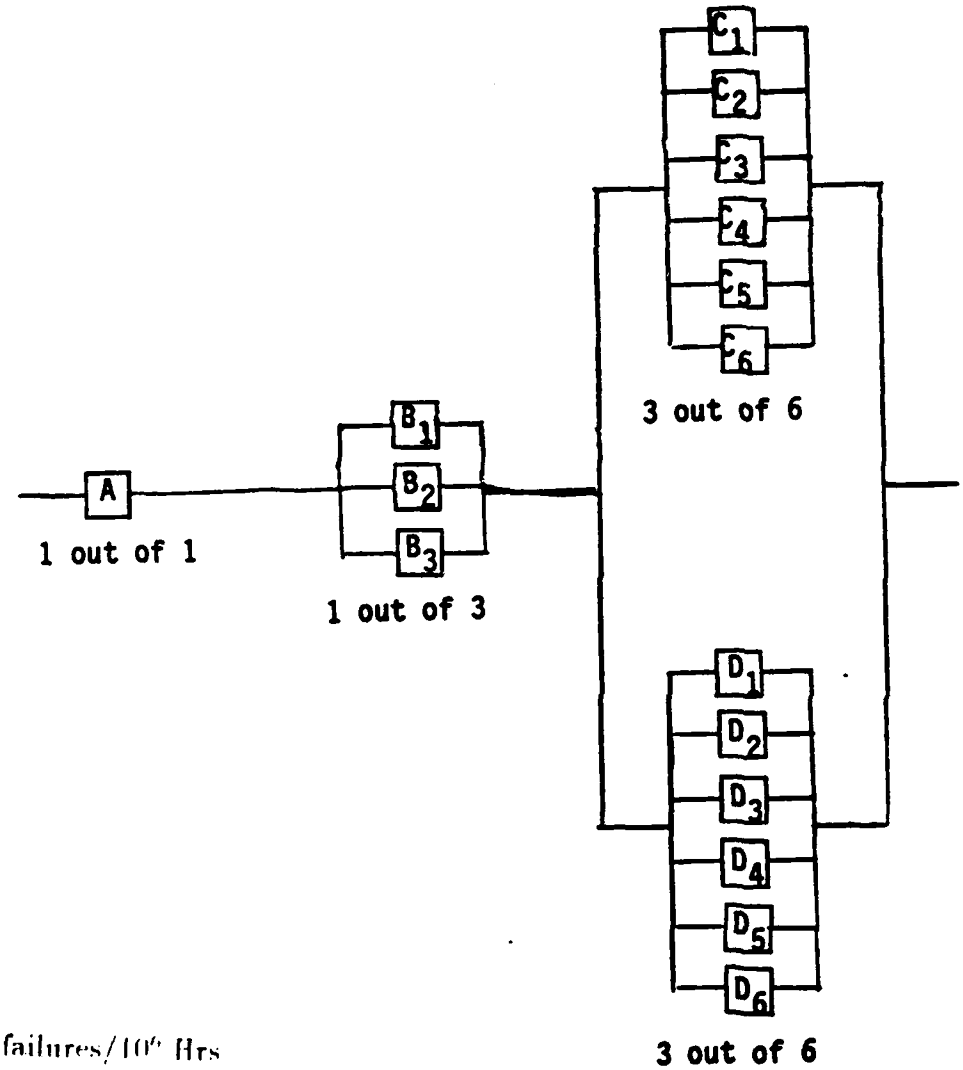
PRIMITIVE DESCR. NO NAME	TRANSITION TYPE	TRANSITION AND MODE DESCRIPTION FROM MODE(NO/NAME)	TO MODE(NO/NAME)
2 punit	failure	1 up	2 ft
	control	2 ft	4 off
	delay/warmup	2 ft	3 sf
	control	3 sf	1 up
	control	4 off	1 up
3 punit	failure	1 up	2 ft
	control	2 ft	4 off
	delay/warmup	2 ft	3 sf
	control	3 sf	1 up
	control	4 off	1 up
4 dunit	control	1 up	2 fdet
	failure	1 up	3 fail
	control	2 fdet	1 up
	control	3 fail	1 up
5 dunit	control	1 up	2 fdet
	failure	1 up	3 fail
	control	2 fdet	1 up
	control	3 fail	1 up
6 r	failure	1 up	2 fail
	control	2 fail	1 up
9 gt	control	1 one	2 two
	control	2 two	1 one
10 gt	control	1 one	2 two
	control	2 two	1 one
12 gt	control	1 one	2 two
	control	2 two	1 one

PRIMITIVE NO NAME	MODE NO	AVERAGE TIME	STANDARD DEVIATION	NON-0 RUNS	AVAILABILITY	UNAVAILABILITY	RELIABILITY
2 punit	1	1.01E+03	1.01953926E+01	10000	1.01224388E-02	9.89877561E-01	0.00000000E+00
	2	1.65E-04	3.66259883E-06	10000	1.64514160E-09	9.99999998E-01	0.00000000E+00
	3	1.65E+04	3.66874359E+02	0	1.64780759E-01	8.35219241E-01	1.00000000E+00
	4	8.25E+04	3.70711914E+02	0	8.25096801E-01	1.74903199E-01	1.00000000E+00
3 punit	1	9.91E+02	1.00548334E+01	10000	9.90854750E-03	9.90091452E-01	0.00000000E+00
	2	1.62E-04	3.63815843E-06	10000	1.61775970E-09	9.99999998E-01	0.00000000E+00
	3	1.62E+04	3.64578003E+02	0	1.62107004E-01	8.37892996E-01	1.00000000E+00
	4	8.28E+04	3.68277252E+02	0	8.27984447E-01	1.72015553E-01	1.00000000E+00
4 dunit	1	8.43E+02	8.48742390E+00	10000	8.43066359E-03	9.91569336E-01	0.00000000E+00
	2	8.25E+04	3.70711914E+02	0	8.25096801E-01	1.74903199E-01	1.00000000E+00
	3	1.66E+04	3.70616577E+02	0	1.66472535E-01	8.33527465E-01	1.00000000E+00
5 dunit	1	8.31E+02	8.47834969E+00	10000	8.31386325E-03	9.91686137E-01	0.00000000E+00
	2	8.28E+04	3.68277252E+02	0	8.27984447E-01	1.72015553E-01	1.00000000E+00
	3	1.64E+04	3.68142181E+02	0	1.63701690E-01	8.36298310E-01	1.00000000E+00
6 r	1	1.00E+05	2.31072807E+00	2	9.99976446E-01	2.35544219E-05	9.99800000E-01

	2	2.36E+00	2.31072807E+00	0	2.35544219E-05	9.99976446E-01	1.00000000E+00
9 gt	1	9.85E+04	1.13733826E+01	0	9.84926272E-01	1.50737281E-02	1.00000000E+00
	2	1.51E+03	1.13733826E+01	10000	1.50737284E-02	9.84926272E-01	0.00000000E+00
10 gt	1	3.00E+04	4.52278503E+02	0	2.99577509E-01	7.00422491E-01	1.00000000E+00
	2	7.00E+04	4.52278503E+02	3050	7.00422492E-01	2.99577508E-01	6.95000000E-01
12 gt	1	9.86E+04	1.09782743E+01	0	9.85851640E-01	1.41483601E-02	1.00000000E+00
	2	$\boxed{1.41E+03}$	1.09782753E+01	10000	1.41483605E-02	9.85851640E-01	0.00000000E+00

PRIMITIVE NO NAME	TRANS. FR	TO	TOTAL NO OCCURNCS	NON-ZERO RUNS	MEAN TIME BETW TRNS	RELIABILITY	UNRELIABILITY
2 punit	1	2	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00
	2	4	8321	8321	1.20E+05	1.67900000E-01	8.32100000E-01
	2	3	1679	1679	5.96E+05	8.32100000E-01	1.67900000E-01
	3	1	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
	4	1	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
3 punit	1	2	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00
	2	4	8349	8349	1.20E+05	1.65100000E-01	8.34900000E-01
	2	3	1651	1651	6.06E+05	8.34900000E-01	1.65100000E-01
	3	1	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
	4	1	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
4 dunit	1	2	8321	8321	1.20E+05	1.67900000E-01	8.32100000E-01
	1	3	1679	1679	5.96E+05	8.32100000E-01	1.67900000E-01
	2	1	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
	3	1	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
5 dunit	1	2	8349	8349	1.20E+05	1.65100000E-01	8.34900000E-01
	1	3	1651	1651	6.06E+05	8.34900000E-01	1.65100000E-01
	2	1	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
	3	1	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
6 r	1	2	2	2	5.00E+08	9.99800000E-01	2.00000000E-04
	2	1	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
9 gt	1	2	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
	2	1	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00
10 gt	1	2	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
	2	1	3050	3050	3.28E+05	6.95000000E-01	3.05000000E-01
12 gt	1	2	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
	2	1	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00

Example 6: Active Redundancy (Dissimiliar Failure Rates and Nested Redundancy). Repair Philosophy Assume that corrective repair is deferred until a critical failure occurs.



λ_A = 70 failures/10^6 Hrs
λ_{B1} = 50 failures/10^6 Hrs
$\lambda_{B2} = \lambda_{B3}$ 70 failures/10^6 Hrs
$\lambda_{C1} = \lambda_{C2} \ldots \lambda_{C6}$ 50 failures/10^6 Hrs
$\lambda_{D1} = \lambda_{D2} \ldots \lambda_{D6}$ 60 failures/10^6 Hrs

Compute:

1. MTBCF

2. Reliability at time $t = 720$ Hr

Example 6

This system shows an example of multiple failure rates in series/parallel systems. For the system to operate, the A unit must be up, the B-Group must be up (1 out of 3) and either the C-Group or the D-Group must be up.

Figure 6-1 shows the top level diagram for this system. The blocks A, B, C, and D represent the system components and the detailed diagrams are shown in figures 6-2 through 6-4. Each component has a repair trigger which is reset by the RP block. the RP block is triggered by block GT-12.

The B-Group (see figure 6-3) is modeled using several modes which define which B subunit fails.

The C and D groups are modeled in a similar fashion. However, the model is simpler because all subunits have the same failure rate. If all subunits have the same failure rate, the details of which subunit fails may not be required. Since a critical failure occurs after the fourth failure and the block will be repaired, the nodes with 1 or 2 subunits up are not modeled.

The simulation in figure 6-1 was run for 100,000 missions with 720 hours/ mission to compute the reliability. To compute the MBTCF, a long run (100,000 hours) was conducted.

The reliability after 720 hours is obtained from GT-12. A value of 0.9518 is obtained. The MTBCF from the 100,000 hour run was 9690 hours.

Other repair methods can be simulated by modification of the top level diagram. For example, repair of each group can be carried out only when the group fails. This could be done using an RP block for each group (A, B, C or D). In this case the RP block would be driven by a GT block which itself is driven by the group output.

Example 6

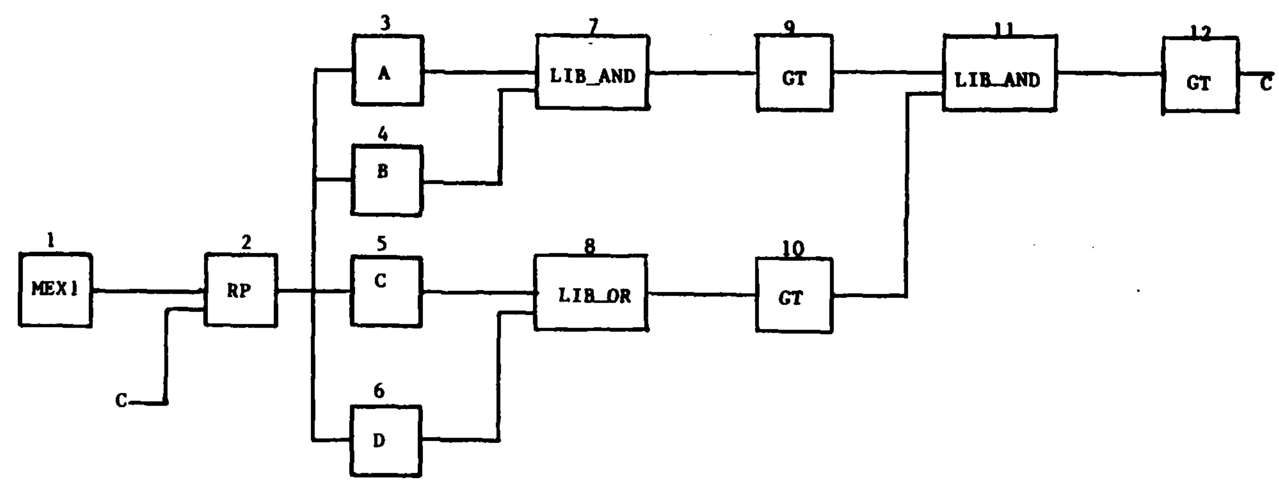
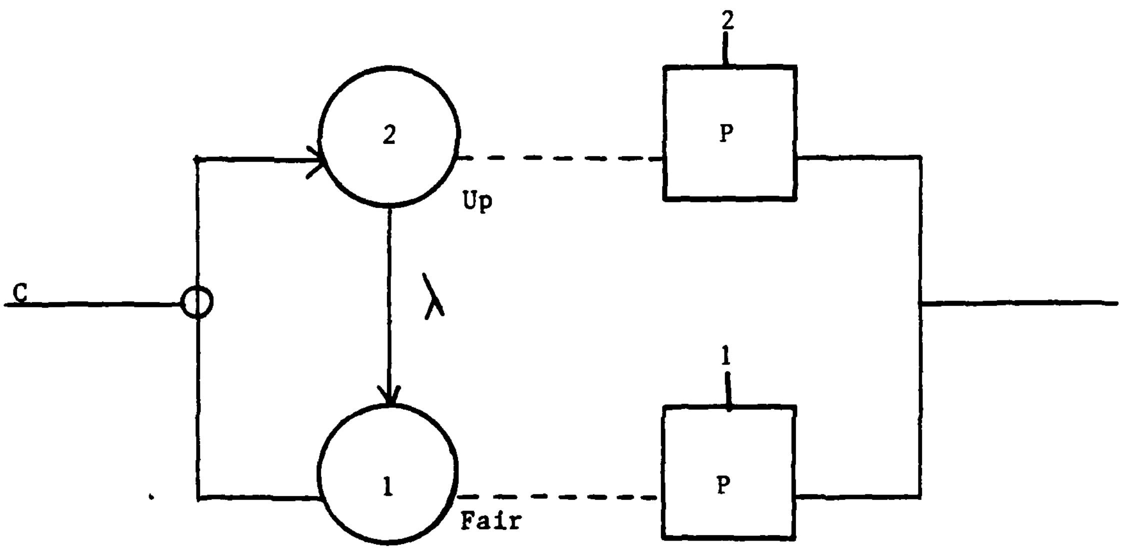


Figure 6-1

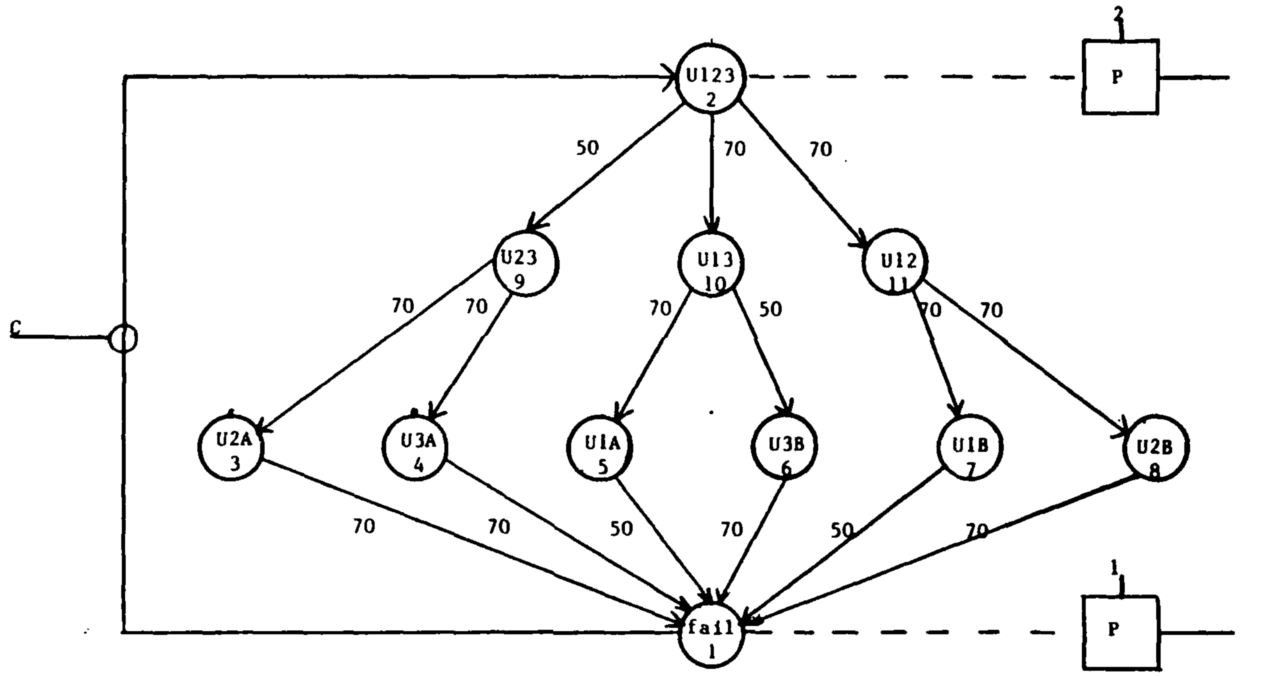
A - Unit



λ = 70 E-6

Figure 6-2

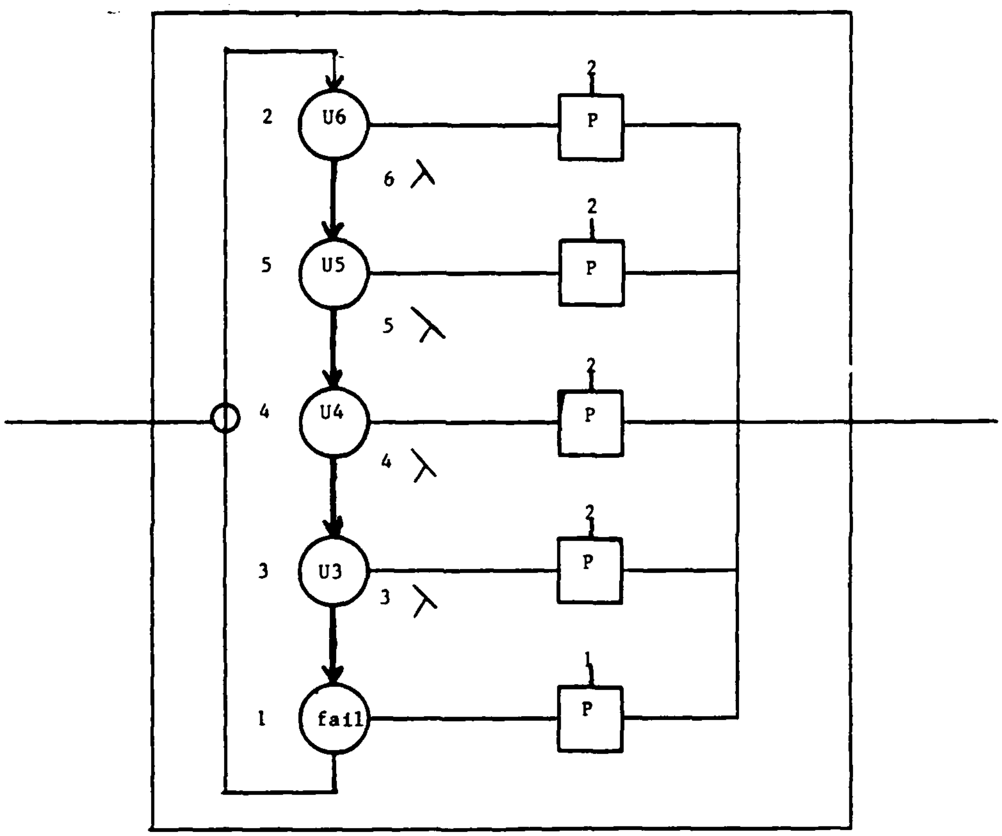
B - Unit



Output for all nodes is a 2 except for node "fail". Node "fail" output is 1.0.

Figure 6-3

C Unit and D Unit



λ = 50 E-6 for C unit

λ = 60 E-6 for D unit

Figure 6-4

SIMULATION RESULTS

Simulation name: ex6
Number of simulation runs: 100000
Single run duration: 720.0000
Number of monitored primitives: 11
Random number seed: 12345

PRIMITIVE DESCR. NO NAME	TRANSITION TYPE	TRANSITION AND MODE DESCRIPTION FROM MODE(NO/NAME)	TO MODE(NO/NAME)
2 rp	delay/warmup	1 rep	2 idle
	control	2 idle	1 rep
3 a	control	1 fail	2 up
	failure	2 up	1 fail
4 b	control	1 fail	2 u123
	failure	2 u123	9 u23
	failure	2 u123	10 u13
	failure	2 u123	11 u12
	failure	3 u2a	1 fail
	failure	4 u3a	1 fail
	failure	5 u1a	1 fail
	failure	6 u3b	1 fail
	failure	7 u1b	1 fail
	failure	8 u2b	1 fail
	failure	9 u23	3 u2a
	failure	9 u23	4 u3a
	failure	10 u13	5 u1a
	failure	10 u13	6 u3b
	failure	11 u12	7 u1b
	failure	11 u12	8 u2b
5 c	control	1 fail	2 u6
	failure	2 u6	5 u5
	failure	3 u3	1 fail
	failure	4 u4	3 u3
	failure	5 u5	4 u4
6 d	control	1 fail	2 u6
	failure	2 u6	5 u5
	failure	3 u3	1 fail
	failure	4 u4	3 u3
	failure	5 u5	4 u4
9 gt	control	1 one	2 two
	control	2 two	1 one
10 gt	control	1 one	2 two
	control	2 two	1 one
12 gt	control	1 one	2 two
	control	2 two	1 one

PRIMITIVE NO NAME	MODE NO	AVERAGE TIME	STANDARD DEVIATION	NON-0 RUNS	AVAILABILITY	UNAVAILABILITY	RELIABILITY
2 rp	1	4.91E-05	6.97611426E-07	4820	6.81961566E-08	9.99999932E-01	9.51800000E-01
	2	7.20E+02	6.86447720E-07	4820	9.99999932E-01	6.80720237E-08	9.51800000E-01
3 a	1	0.00E+00	0.00000000E+00	4808	0.00000000E+00	1.00000000E+00	9.51920000E-01
	2	7.20E+02	9.76562475E-09	4808	1.00000000E+00	-1.19504643E-10	9.51920000E-01
4 b	1	0.00E+00	0.00000000E+00	12	0.00000000E+00	1.00000000E+00	9.99880000E-01
	2	6.72E+02	4.57601607E-01	12831	9.33916970E-01	6.60830298E-02	8.71690000E-01
	3	1.95E-01	2.71289553E-02	4	2.70977577E-04	9.99729022E-01	9.99960000E-01

	4	2.05E-01	2.76924763E-02	3	2.84948381E-04	9.99715052E-01	9.99970000E-01
	5	2.89E-01	3.10794674E-02	1	4.01075396E-04	9.99598925E-01	9.99990000E-01
	6	1.96E-01	2.59966049E-02	2	2.72742651E-04	9.99727257E-01	9.99980000E-01
	7	2.89E-01	3.27289589E-02	1	4.01138390E-04	9.99598862E-01	9.99990000E-01
	8	1.68E-01	2.43053902E-02	1	2.33483991E-04	9.99766516E-01	9.99990000E-01
	9	1.20E+01	2.37136617E-01	162	1.67124742E-02	9.83287526E-01	9.98380000E-01
	10	1.72E+01	2.82686919E-01	217	2.38315809E-02	9.76168419E-01	9.97830000E-01
	11	1.70E+01	2.80698210E-01	186	2.36746085E-02	9.76325391E-01	9.98140000E-01
5 c	1	2.91E-03	1.81847392E-03	0	4.04513635E-06	9.99995955E-01	1.00000000E+00
	2	6.48E+02	5.47498882E-01	19288	9.00121566E-01	9.98784342E-02	8.07120000E-01
	3	1.61E-01	2.16850098E-02	3	2.23680947E-04	9.99776319E-01	9.99970000E-01
	4	4.19E+00	1.21623851E-01	89	5.81284439E-03	9.94187156E-01	9.99110000E-01
	5	6.76E+01	5.23845911E-01	1731	9.38378643E-02	9.06162136E-01	9.82690000E-01
6 d	1	8.42E-03	4.67100507E-03	0	1.16955287E-05	9.99988304E-01	1.00000000E+00
	2	6.34E+02	5.90299189E-01	22813	8.80573717E-01	1.19426283E-01	7.71870000E-01
	3	1.98E-01	2.31946930E-02	5	2.74960913E-04	9.99725039E-01	9.99950000E-01
	4	5.84E+00	1.43948555E-01	124	8.10753921E-03	9.91892461E-01	9.98760000E-01
	5	7.99E+01	5.61347604E-01	2419	1.11032088E-01	8.88967912E-01	9.75810000E-01
9 gt	1	0.00E+00	0.00000000E+00	4820	0.00000000E+00	1.00000000E+00	9.51800000E-01
	2	7.20E+02	9.76562475E-09	4820	1.00000000E+00	-1.19292724E-10	9.51800000E-01
10 gt	1	0.00E+00	0.00000000E+00	0	0.00000000E+00	1.00000000E+00	1.00000000E+00
	2	7.20E+02	0.00000000E+00	0	1.00000000E+00	0.00000000E+00	1.00000000E+00
12 gt	1	0.00E+00	0.00000000E+00	4820	0.00000000E+00	1.00000000E+00	9.51800000E-01
	2	7.20E+02	9.76562475E-09	4820	1.00000000E+00	-1.19292724E-10	9.51800000E-01

PRIMITIVE NO NAME	TRANS. FR	TO	TOTAL NO OCCURNCS	NON-ZERO RUNS	MEAN TIME BETW TRNS	RELIABILITY	UNRELIABILITY
2 rp	1	2	4926	4820	1.46E+04	9.51800000E-01	4.82000000E-02
	2	1	4926	4820	1.46E+04	9.51800000E-01	4.82000000E-02
3 a	1	2	4914	4808	1.47E+04	9.51920000E-01	4.80800000E-02
	2	1	4914	4808	1.47E+04	9.51920000E-01	4.80800000E-02
4 b	1	2	12	12	6.00E+06	9.99880000E-01	1.20000000E-04
	2	9	3376	3376	2.13E+04	9.66240000E-01	3.37600000E-02
	2	10	4721	4721	1.53E+04	9.52790000E-01	4.72100000E-02
	2	11	4734	4734	1.52E+04	9.52660000E-01	4.73400000E-02
	3	1	4	4	1.80E+07	9.99960000E-01	4.00000000E-05
	4	1	3	3	2.40E+07	9.99970000E-01	3.00000000E-05
	5	1	1	1	7.20E+07	9.99990000E-01	1.00000000E-05
	6	1	2	2	3.60E+07	9.99980000E-01	2.00000000E-05
	7	1	1	1	7.20E+07	9.99990000E-01	1.00000000E-05
	8	1	1	1	7.20E+07	9.99990000E-01	1.00000000E-05
	9	3	77	77	9.35E+05	9.99230000E-01	7.70000000E-04
	9	4	85	85	8.47E+05	9.99150000E-01	8.50000000E-04
	10	5	128	128	5.63E+05	9.98720000E-01	1.28000000E-03
	10	6	89	89	8.09E+05	9.99110000E-01	8.90000000E-04
	11	7	117	117	6.15E+05	9.98830000E-01	1.17000000E-03
	11	8	69	69	1.04E+06	9.99310000E-01	6.90000000E-04
5 c	1	2	0	0	7.20E+02	1.00000000E+00	0.00000000E+00
	2	5	19288	19288	3.73E+03	8.07120000E-01	1.92880000E-01
	3	1	3	3	2.40E+07	9.99970000E-01	3.00000000E-05
	4	3	89	89	8.09E+05	9.99110000E-01	8.90000000E-04
	5	4	1731	1731	4.16E+04	9.82690000E-01	1.73100000E-02
6 d	1	2	0	0	7.20E+02	1.00000000E+00	0.00000000E+00
	2	5	22813	22813	3.16E+03	7.71870000E-01	2.28130000E-01

	3	1	5	5	1.44E+07	9.99950000E-01	5.00000000E-05
	4	3	124	124	5.81E+05	9.98760000E-01	1.24000000E-03
	5	4	2419	2419	2.98E+04	9.75810000E-01	2.41900000E-02
9 gt	1	2	4926	4820	1.46E+04	9.51800000E-01	4.82000000E-02
	2	1	4926	4820	1.46E+04	9.51800000E-01	4.82000000E-02
10 gt	1	2	0	0	7.20E+02	1.00000000E+00	0.00000000E+00
	2	1	0	0	7.20E+02	1.00000000E+00	0.00000000E+00
12 gt	1	2	4926	4820	1.46E+04	9.51800000E-01	4.82000000E-02
	2	1	4926	4820	1.46E+04	$\boxed{9.51800000E-01}$	4.82000000E-02

System Reliability
for 720 hour mission

SIMULATION RESULTS (Repair Deactivated)

Simulation name: ex6
Number of simulation runs: 10000
Single run duration: 100000.0
Number of monitored primitives: 11
Random number seed: 12345

PRIMITIVE DESCR. NO NAME	TRANSITION TYPE	TRANSITION AND MODE DESCRIPTION FROM MODE(NO/NAME)	TO MODE(NO/NAME)
2 rp	delay/warmup	1 rep	2 idle
	control	2 idle	1 rep
3 a	control	1 fail	2 up
	failure	2 up	1 fail
4 b	control	1 fail	2 u123
	failure	2 u123	9 u23
	failure	2 u123	10 u13
	failure	2 u123	11 u12
	failure	3 u2a	1 fail
	failure	4 u3a	1 fail
	failure	5 u1a	1 fail
	failure	6 u3b	1 fail
	failure	7 u1b	1 fail
	failure	8 u2b	1 fail
	failure	9 u23	3 u2a
	failure	9 u23	4 u3a
	failure	10 u13	5 u1a
	failure	10 u13	6 u3b
	failure	11 u12	7 u1b
	failure	11 u12	8 u2b
5 c	control	1 fail	2 u6
	failure	2 u6	5 u5
	failure	3 u3	1 fail
	failure	4 u4	3 u3
	failure	5 u5	4 u4
6 d	control	1 fail	2 u6
	failure	2 u6	5 u5
	failure	3 u3	1 fail
	failure	4 u4	3 u3
	failure	5 u5	4 u4
9 gt	control	1 one	2 two
	control	2 two	1 one
10 gt	control	1 one	2 two
	control	2 two	1 one
12 gt	control	1 one	2 two
	control	2 two	1 one

PRIMITIVE NO NAME	MODE NO	AVERAGE TIME	STANDARD DEVIATION	NON-0 RUNS	AVAILABILITY	UNAVAILABILITY	RELIABILITY
2 rp	1	1.00E-03	0.00000000E+00	10000	1.00000005E-08	9.99999990E-01	0.00000000E+00
	2	1.00E+05	0.00000000E+00	0	1.00000000E+00	0.00000000E+00	1.00000000E+00
3 a	1	8.57E+04	1.41094315E+02	0	8.57358278E-01	1.42641722E-01	1.00000000E+00
	2	1.43E+04	1.41094315E+02	9994	1.42641726E-01	8.57358274E-01	6.00000000E-04
4 b	1	7.00E+04	1.92768036E+02	0	6.99547007E-01	3.00452993E-01	1.00000000E+00
	2	5.23E+03	5.25273056E+01	10000	5.22738044E-02	9.47726196E-01	0.00000000E+00
	3	1.88E+03	7.00491409E+01	1325	1.87620265E-02	9.81237974E-01	8.67500000E-01

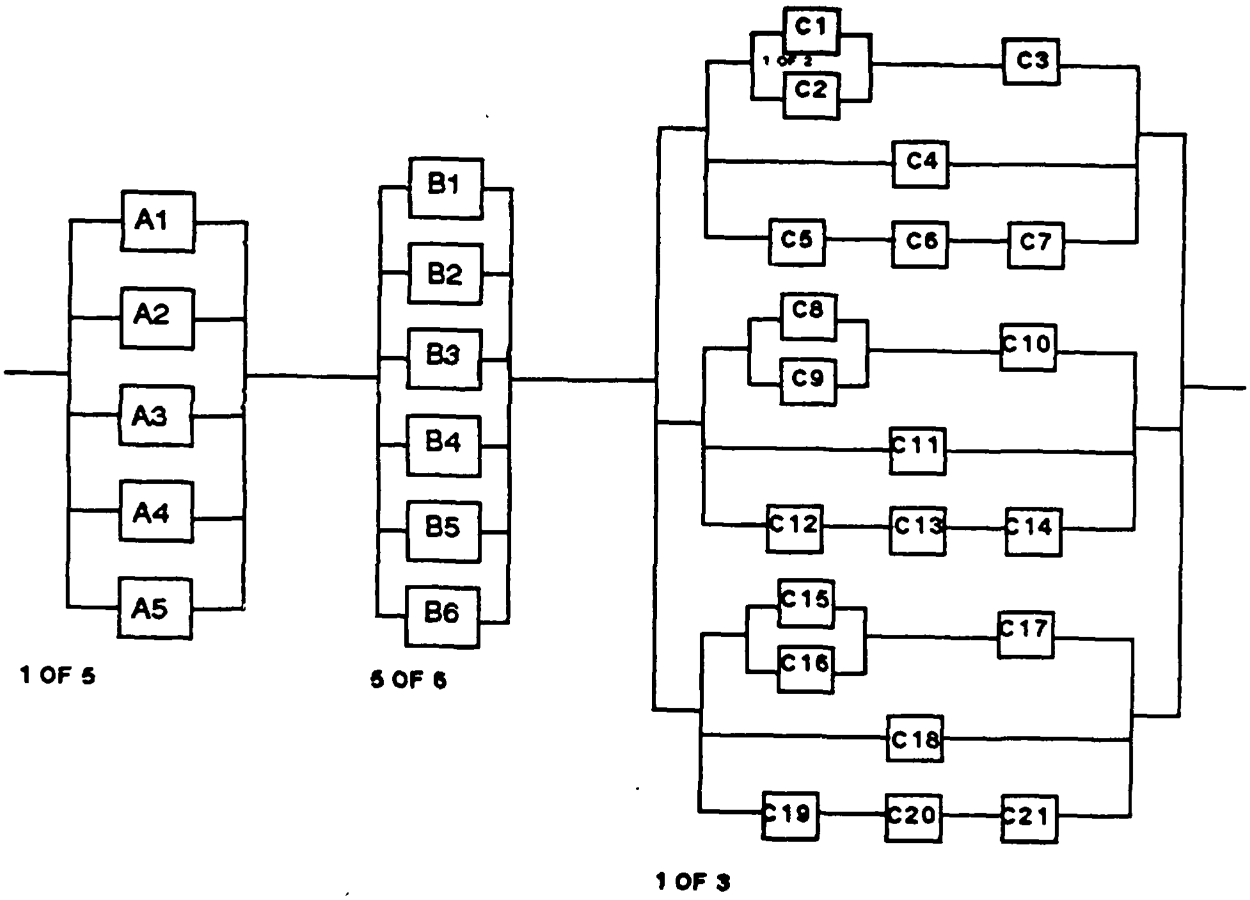
	4	1.95E+03	7.27298965E+01	1296	1.94919814E-02	9.80508019E-01	8.70400000E-01
	5	4.33E+03	1.20814728E+02	2170	4.33183451E-02	9.56681655E-01	7.83000000E-01
	6	2.14E+03	7.54524155E+01	1498	2.13932856E-02	9.78606714E-01	8.50200000E-01
	7	4.15E+03	1.17180611E+02	2100	4.14629787E-02	9.58537021E-01	7.90000000E-01
	8	2.30E+03	8.03678131E+01	1512	2.30291091E-02	9.76970891E-01	8.48800000E-01
	9	1.91E+03	4.99272194E+01	2629	1.91217412E-02	9.80878259E-01	7.37100000E-01
	10	3.06E+03	6.38631058E+01	3711	3.06420161E-02	9.69357984E-01	6.28900000E-01
	11	3.10E+03	6.51591644E+01	3660	3.09577115E-02	9.69042288E-01	6.34000000E-01
5 c	1	8.10E+04	9.83509140E+01	0	8.10284643E-01	1.89715357E-01	1.00000000E+00
	2	3.33E+03	3.36165161E+01	10000	3.32539066E-02	9.66746093E-01	0.00000000E+00
	3	6.66E+03	6.63718262E+01	10000	6.66477107E-02	9.33352289E-01	0.00000000E+00
	4	4.99E+03	4.97854080E+01	10000	4.98624351E-02	9.50137565E-01	0.00000000E+00
	5	4.00E+03	4.02774773E+01	10000	3.99513118E-02	9.60048688E-01	0.00000000E+00
6 d	1	8.42E+04	8.24928970E+01	0	8.41548721E-01	1.58451279E-01	1.00000000E+00
	2	2.83E+03	2.87625904E+01	10000	2.82740026E-02	9.71725997E-01	0.00000000E+00
	3	5.56E+03	5.64952049E+01	10000	5.56009456E-02	9.44399054E-01	0.00000000E+00
	4	4.14E+03	4.08720512E+01	10000	4.14281078E-02	9.58571892E-01	0.00000000E+00
	5	3.31E+03	3.31829987E+01	10000	3.31482306E-02	9.66851769E-01	0.00000000E+00
9 gt	1	8.88E+04	9.57832642E+01	0	8.88092278E-01	1.11907722E-01	1.00000000E+00
	2	1.12E+04	9.57832718E+01	10000	1.11907726E-01	8.88092274E-01	0.00000000E+00
10 gt	1	7.75E+04	9.28444595E+01	0	7.75196367E-01	2.24803633E-01	1.00000000E+00
	2	2.25E+04	9.28444595E+01	10000	2.24803641E-01	7.75196359E-01	0.00000000E+00
12 gt	1	9.03E+04	7.00855713E+01	0	9.03105891E-01	9.68941090E-02	1.00000000E+00
	2	$\boxed{9.69E+03}$	7.00855713E+01	10000	9.68941131E-02	9.03105887E-01	0.00000000E+00

System MTBCF

PRIMITIVE NO NAME	TRANS. FR	TO	TOTAL NO OCCURNCS	NON-ZERO RUNS	MEAN TIME BETW TRNS	RELIABILITY	UNRELIABILITY
2 rp	1	2	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00
	2	1	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
3 a	1	2	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
	2	1	9994	9994	1.00E+05	6.00000000E-04	9.99400000E-01
4 b	1	2	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
	2	9	2629	2629	3.80E+05	7.37100000E-01	2.62900000E-01
	2	10	3711	3711	2.69E+05	6.28900000E-01	3.71100000E-01
	2	11	3660	3660	2.73E+05	6.34000000E-01	3.66000000E-01
	3	1	1325	1325	7.55E+05	8.67500000E-01	1.32500000E-01
	4	1	1296	1296	7.72E+05	8.70400000E-01	1.29600000E-01
	5	1	2170	2170	4.61E+05	7.83000000E-01	2.17000000E-01
	6	1	1498	1498	6.68E+05	8.50200000E-01	1.49800000E-01
	7	1	2100	2100	4.76E+05	7.90000000E-01	2.10000000E-01
	8	1	1512	1512	6.61E+05	8.48800000E-01	1.51200000E-01
	9	3	1329	1329	7.52E+05	8.67100000E-01	1.32900000E-01
	9	4	1300	1300	7.69E+05	8.70000000E-01	1.30000000E-01
	10	5	2206	2206	4.53E+05	7.79400000E-01	2.20600000E-01
	10	6	1505	1505	6.64E+05	8.49500000E-01	1.50500000E-01
	11	7	2136	2136	4.68E+05	7.86400000E-01	2.13600000E-01
	11	8	1524	1524	6.56E+05	8.47600000E-01	1.52400000E-01
5 c	1	2	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
	2	5	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00
	3	1	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00
	4	3	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00
	5	4	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00
6 d	1	2	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
	2	5	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00

	3	1	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00
	4	3	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00
	5	4	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00
9 gt	1	2	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
	2	1	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00
10 gt	1	2	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
	2	1	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00
12 gt	1	2	0	0	1.00E+05	1.00000000E+00	0.00000000E+00
	2	1	10000	10000	1.00E+05	0.00000000E+00	1.00000000E+00

Example 7: A More Complex System (Multiple Mission Phases) – All Active Redundancy. Repair Philosophy Assume that corrective repair is deferred until a critical failure occurs.



Phase 1 (T = 10Hr)

$\lambda_{A1} = \lambda_{A2} = \ldots \lambda_{A5} = 100$ failures/10^6 Hr

$\lambda_{B1} = \lambda_{B2} = \ldots \lambda_{B6} = 50$ failures/10^6 Hr

$\lambda_{C1} = \lambda_{C2} = \ldots \lambda_{C21} = 75$ failures/10^6 Hr

Phase 2 (T = 5 Hr)

$\lambda_{A1} = \lambda_{A2} = \ldots \lambda_{A5} = 200$ failures/10^6 Hr

$\lambda_{B1} = \lambda_{B2} = \ldots \lambda_{B6} = 25$ failures/10^6 Hr

$\lambda_{C1} = \lambda_{C2} = \ldots \lambda_{C21} = 50$ failures/10^6 Hr

Phase 3 (T = 2 Hr)

$\lambda_{A1} = \lambda_{A2} = \ldots \lambda_{A5} = 75$ failures/10^6 Hr

$\lambda_{B1} = \lambda_{B2} = \ldots \lambda_{B6} = 75$ failures/10^6 Hr

$\lambda_{C1} = \lambda_{C2} = \ldots \lambda_{C21} = 25$ failures/10^6 Hr

Reliability at each Phase (T = 10, 15, 17)

Example 7

The overall system is composed of three types of subunits (called A, B and C) which are in series and parallel configurations. Each subunit has a mission time dependent failure rate. The overall system operation requires the following:

A–Group (one out of five A units must be up)
B–Group (five out of six B units must be up)
C–Group (one out of three C subgroups must be up)

By inspection of the system diagrams, the greatest contribution to system failure is the B–Group. This is because system failure occurs after only two B unit failures. In constrast, it takes five A unit failures for system failure to occur. The C-Group is more complex because of the series and parallel nature. However, since all three C-subgroups must fail to cause system failure, the C-group is expected to have a small contribution to the system failure rate.

The FASTER diagram for the system is shown in four figures due to the large number of blocks required. The first two diagrams 7-1 and 7-2 show the A-Group, B-Group and C-Group in detail. Figure 7-3 shows the structure of the A, B and C primitives which have mission dependent failure rates. For the A and B groups each unit outputs a zero (0) if it is up and a one (1) if it fails. All outputs are added together and a threshold primitive changes mode when a certain number of failures occur. The C units output a two (2) when they are up and a one (1) when they fail. A combination of ANDS and ORS are used to define C group operation. Figure 7-4 shows the overall system diagram. For the system to be operational, all three groups (A, B and C) must be operational. Timer blocks (GT) are used to keep track of system operation. The TRS and TRSA blocks are threshold blocks which output a fail value (1) when the number of failures (which is an input) exceeds a threshold value. For this example, the threshold value for TRS is 4.5 (which outputs a "1" after five failures) and the threshold for TRSA is 1.5 (which outputs a "1" after two failures).

Example 7 shows a case where a unique well defined value for MTBCF does not exist. This is because of the time dependence of the critical failure rate (see example 4 comment) and the mission dependent subunit failure rate. As discussed in example 4, a time dependent failure rate requires a long mission time. However, the failure rates for the primitive subunits are not defined beyond 17 hours. Only if assumptions about the failure rates beyond 17 hours are made can an MTBCF be computed using a long mission. For this reason, MTBCF values are not obtained for example 7.

Results for a 17 hour mission are obtained using 100,000 runs. Inspection of these results show that the number of individual unit failures compare with results which can be ob-

tained by a simple calculation. For example, in phase one (10 hours) with 100,000 runs the total time is 1,000,000 hours. The expected total numbers of failures are: 100 for A units, 50 for B units, and 75 for C units. The FASTER output predicts these values as the number of transitions from mode 1 to mode 4 for AU, BU and CU. Within statistics, these values agree with expected results.

The FASTER output shows that only one critical failure occurs in 100,000 missions. This failure was due to failure of the B Group. The other groups contribute to the failure rate but their contribution is much less.

A much greater number of runs is needed to obtain good statistics. Due to the complexity of the FASTER diagram and the amount of computer time needed, this was not done. Instead, a simplified diagram containing only the B-Group was run.

To demonstrate that the A and C groups do not make a significant contribution to the system failure, a set of 10,000 runs each of 3,000 hours was run. This insures that multiple failures occur. The blocks GT-65, GT-66 and GT-67 give the numbers of system failures caused by A-Group (21) B-Group (2467) and C-Group (0). As the run time is decreased to 17 hours, the contributions of C and A become even smaller when compared to B.

The FASTER results for B Group evaluation show that for a 17 hour mission, there were only 7 failures in 500,000 missions. This gives a reliability of 0.999986. Even higher reliability values are obtained for 10 and 15 hour missions.

An estimate of the B Group failure rate can be made using the binomial distribution. Assuming a 20 hour mission and a failure rate of 50 X 10^{-6} per hour, the probability of a B unit failure during the mission is 10^{-3}. With six (6) B units, the binomial distribution gives the following:

P (1) = 6 x 10^{-3}
P (2) = 15 x 10^{-6}
P (3) = 20 x 10^{-9}
P (4) = 15 x 10^{-12}
P (5) = 6 x 10^{-15}
P (6) = 1 x 10^{-19}

The FASTER output for the 17 hour mission shows a total number of B unit failures of 2400 which gives a probability of failure of 4.8 x 10^{-3}. Since only 7 system failures occur, (two or more B units fail), the failure probability is 14 x 10^{-6}. These values are similar to the estimated values.

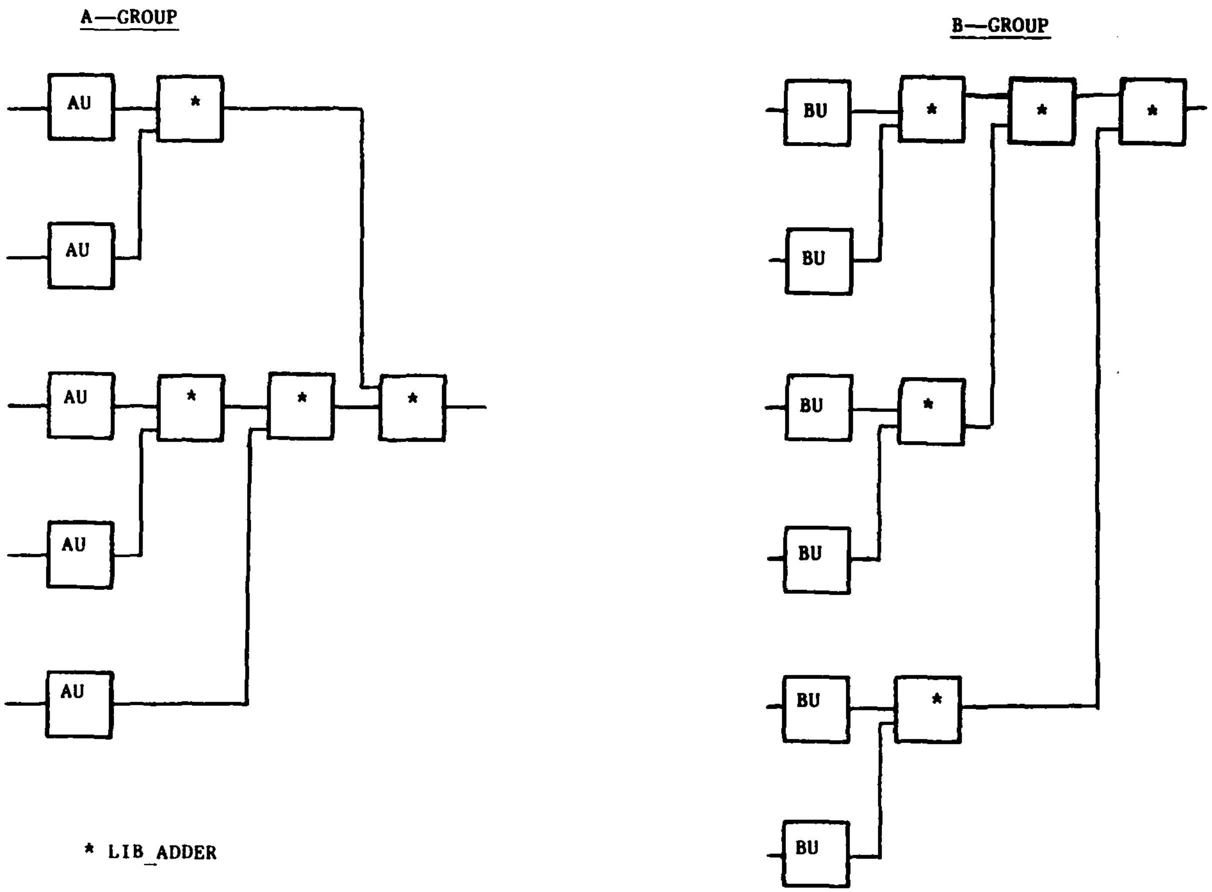


Figure 7—1

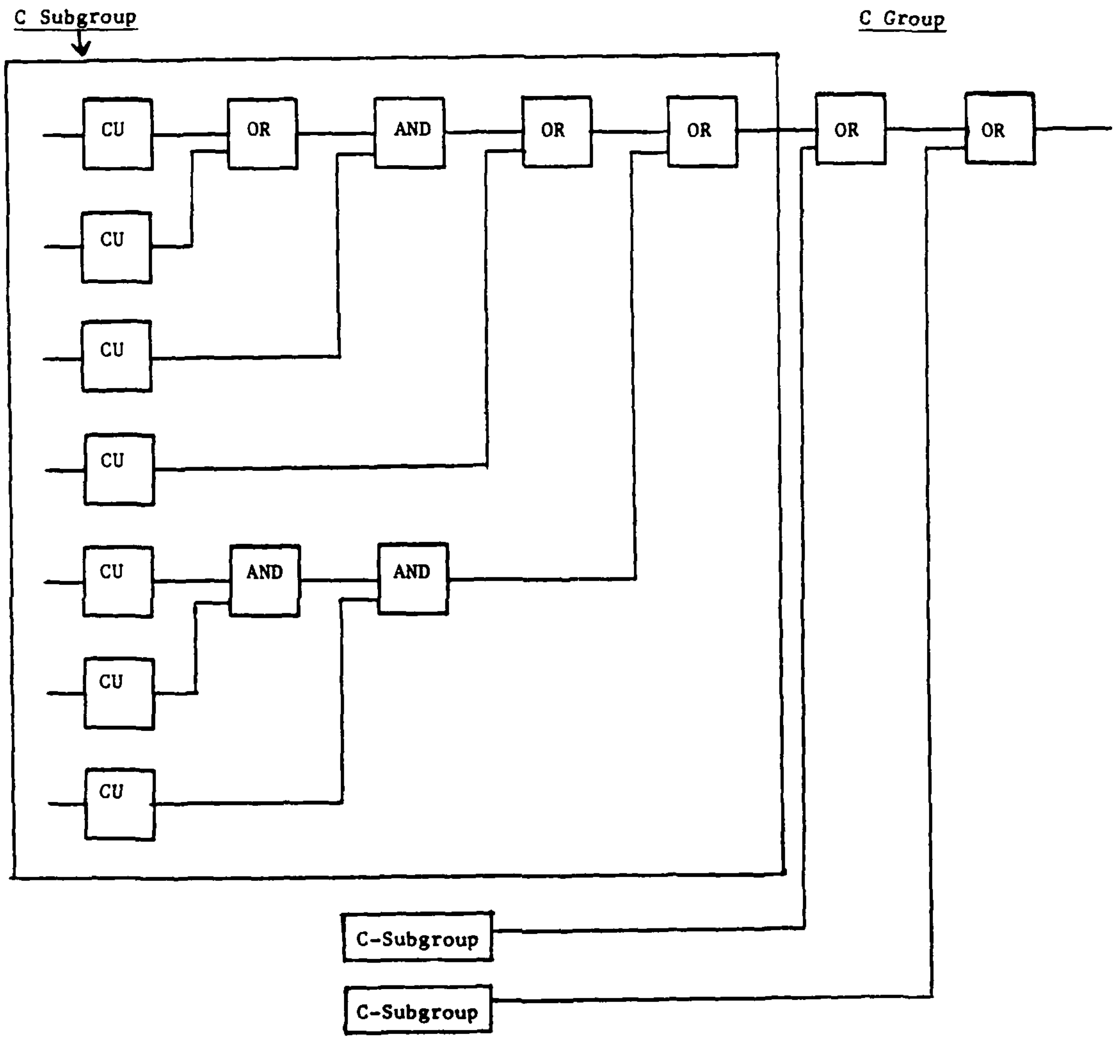

C Subgroup
C Group
CU
OR
AND
OR
OR
OR
OR
CU
CU
CU
CU
AND
AND
CU
CU
C-Subgroup
C-Subgroup

Figure 7—2

AU, BU and CU

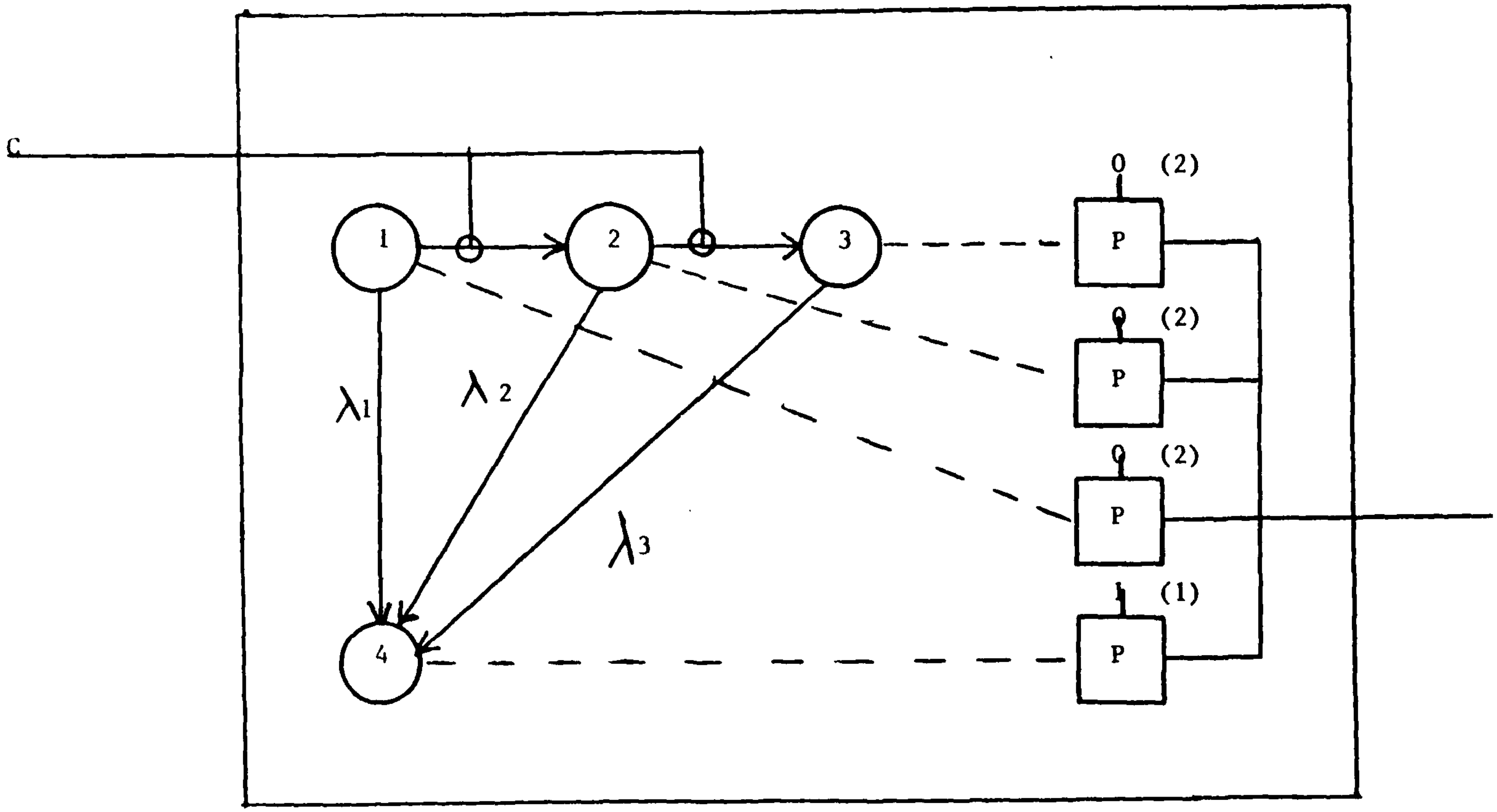


Figure 7-3

Example 7

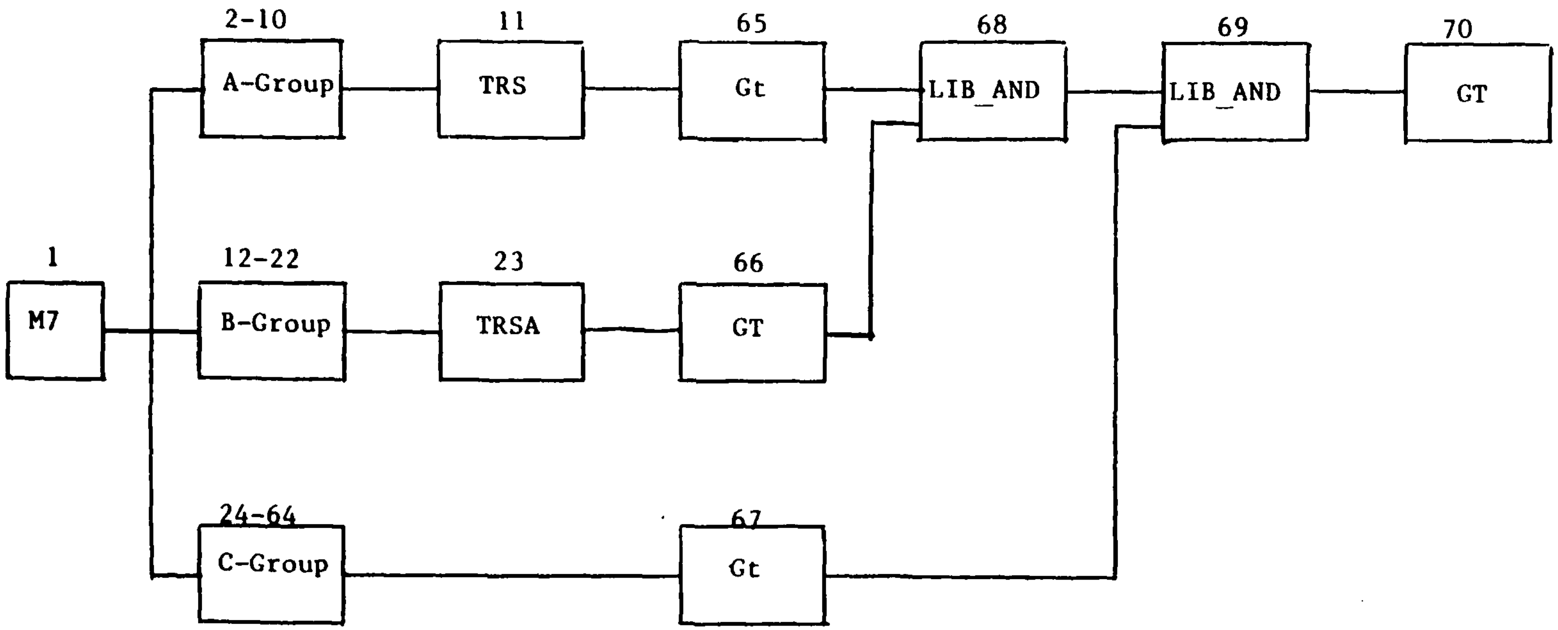


Figure 7-4

SIMULATION RESULTS

Simulation name: M7P
Number of simulation runs: 100000
Single run duration: 17.00000
Number of monitored primitives: 69
Random number seed: 12345

PRIMITIVE DESCR. NO NAME	TRANSITION TYPE	TRANSITION AND MODE DESCRIPTION FROM MODE(NO/NAME)	TO MODE(NO/NAME)
2 au	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
3 au	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
4 au	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
5 au	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
6 au	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
11 trs	threshold	1 up	2 down
12 bu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
13 bu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
14 bu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
15 bu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
16 bu	failure	1 p1	4 fail
	control	1 p1	2 ph2

	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
17 bu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
23 trsa	threshold	1 up	2 down
24 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
25 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
26 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
27 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
28 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
29 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
30 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
37 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
38 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
39 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
40 cu	failure	1 p1	4 fail

	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
41 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
42 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
43 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
50 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
51 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
52 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
53 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
54 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
55 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
56 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
65 gt	control	1 one	2 two
	control	2 two	1 one
66 gt	control	1 one	2 two
	control	2 two	1 one
67 gt	control	1 one	2 two
	control	2 two	1 one

70 gt control 1 one 2 two

control 2 two 1 one

PRIMITIVE NO NAME	MODE NO	AVERAGE TIME	STANDARD DEVIATION	NON-0 RUNS	AVAILABILITY	UNAVAILABILITY	RELIABILITY
2 au	1	1.00E+01	5.68390882E-04	100000	5.87948549E-01	4.12051451E-01	0.00000000E+00
	2	4.99E+00	5.84356603E-04	99896	2.93665833E-01	7.06334167E-01	1.04000000E-03
	3	2.00E+00	2.64556969E-04	18	1.17404332E-01	8.82595668E-01	9.99820000E-01
	4	1.67E-02	1.31659245E-03	0	9.81285453E-04	9.99018715E-01	1.00000000E+00
3 au	1	1.00E+01	5.72757970E-04	100000	5.87947599E-01	4.12052401E-01	0.00000000E+00
	2	4.99E+00	5.60774526E-04	99903	2.93696424E-01	7.06303576E-01	9.70000000E-04
	3	2.00E+00	2.85408547E-04	11	1.17404663E-01	8.82595337E-01	9.99890000E-01
	4	1.62E-02	1.30131852E-03	0	9.51313221E-04	9.99048687E-01	1.00000000E+00
4 au	1	9.99E+00	6.15857600E-04	100000	5.87915184E-01	4.12084816E-01	0.00000000E+00
	2	4.99E+00	5.65549184E-04	99898	2.93688012E-01	7.06311988E-01	1.02000000E-03
	3	2.00E+00	2.86338938E-04	12	1.17402992E-01	8.82597008E-01	9.99880000E-01
	4	1.69E-02	1.35398563E-03	0	9.93811061E-04	9.99006189E-01	1.00000000E+00
5 au	1	9.99E+00	6.22811262E-04	100000	5.87901945E-01	4.12098055E-01	0.00000000E+00
	2	4.99E+00	5.99129417E-04	99886	2.93645871E-01	7.06354129E-01	1.14000000E-03
	3	2.00E+00	2.89166026E-04	18	1.17396732E-01	8.82603268E-01	9.99820000E-01
	4	1.79E-02	1.39376195E-03	0	1.05545238E-03	9.98944548E-01	1.00000000E+00
6 au	1	9.99E+00	5.91494550E-04	100000	5.87926163E-01	4.12073837E-01	0.00000000E+00
	2	4.99E+00	5.70995850E-04	99897	2.93694058E-01	7.06305942E-01	1.03000000E-03
	3	2.00E+00	2.74702761E-04	10	1.17423136E-01	8.82576864E-01	9.99900000E-01
	4	1.63E-02	1.33170211E-03	0	9.56642811E-04	9.99043357E-01	1.00000000E+00
11 trs	1	1.70E+01	0.00000000E+00	0	1.00000000E+00	0.00000000E+00	1.00000000E+00
	2	0.00E+00	0.00000000E+00	0	0.00000000E+00	1.00000000E+00	1.00000000E+00
12 bu	1	1.00E+01	3.94435221E-04	100000	5.88092198E-01	4.11907802E-01	0.00000000E+00
	2	5.00E+00	3.82961472E-04	99945	2.93937996E-01	7.06062004E-01	5.50000000E-04
	3	2.00E+00	1.73077293E-04	21	1.17554884E-01	8.82445116E-01	9.99790000E-01
	4	7.05E-03	8.91406613E-04	0	4.14922176E-04	9.99585078E-01	1.00000000E+00
13 bu	1	1.00E+01	4.20223194E-04	100000	5.88083333E-01	4.11916667E-01	0.00000000E+00
	2	5.00E+00	3.63846018E-04	99950	2.93953990E-01	7.06046010E-01	5.00000000E-04
	3	2.00E+00	1.68389146E-04	22	1.17559260E-01	8.82440740E-01	9.99780000E-01
	4	6.86E-03	8.99987877E-04	0	4.03418406E-04	9.99596582E-01	1.00000000E+00
14 bu	1	1.00E+01	4.10272827E-04	100000	5.88090080E-01	4.11909920E-01	0.00000000E+00
	2	5.00E+00	3.59177677E-04	99953	2.93961324E-01	7.06038676E-01	4.70000000E-04
	3	2.00E+00	1.57474657E-04	12	1.17572214E-01	8.82427786E-01	9.99880000E-01
	4	6.40E-03	8.79646454E-04	0	3.76382230E-04	9.99623618E-01	1.00000000E+00
15 bu	1	1.00E+01	3.86288157E-04	100000	5.88102646E-01	4.11897354E-01	0.00000000E+00
	2	5.00E+00	3.45602370E-04	99957	2.93969547E-01	7.06030453E-01	4.30000000E-04
	3	2.00E+00	1.56402981E-04	14	1.17573220E-01	8.82426780E-01	9.99860000E-01
	4	6.03E-03	8.42198322E-04	0	3.54586790E-04	9.99645413E-01	1.00000000E+00
16 bu	1	1.00E+01	3.81901249E-04	100000	5.88096902E-01	4.11903098E-01	0.00000000E+00
	2	5.00E+00	3.79443198E-04	99948	2.93939944E-01	7.06060056E-01	5.20000000E-04
	3	2.00E+00	1.70661981E-04	17	1.17558078E-01	8.82441922E-01	9.99830000E-01
	4	6.89E-03	8.76845035E-04	0	4.05075221E-04	9.99594925E-01	1.00000000E+00
17 bu	1	1.00E+01	4.09014581E-04	100000	5.88087495E-01	4.11912505E-01	0.00000000E+00
	2	5.00E+00	3.75040894E-04	99948	2.93946263E-01	7.06053737E-01	5.20000000E-04

	3	2.00E+00	1.66449492E-04	14	1.17562559E-01	8.82437441E-01	9.99860000E-01
	4	6.86E-03	8.96467885E-04	0	4.03682940E-04	9.99596317E-01	1.00000000E+00
23 tree	1	1.70E+01	4.40290194E-07	1	9.99999974E-01	2.58995505E-08	9.99990000E-01
	2	4.40E-07	4.40290165E-07	0	2.58995505E-08	9.99999974E-01	1.00000000E+00
24 cu	1	1.00E+01	5.53986174E-04	100000	5.87966989E-01	4.12033011E-01	0.00000000E+00
	2	4.99E+00	4.94570180E-04	99910	2.93819617E-01	7.06180383E-01	9.00000000E-04
	3	2.00E+00	2.10980477E-04	1	1.17515720E-01	8.82484280E-01	9.99990000E-01
	4	1.19E-02	1.19847723E-03	0	6.97673935E-04	9.99302326E-01	1.00000000E+00
25 cu	1	1.00E+01	5.24601957E-04	100000	5.88002134E-01	4.11997866E-01	0.00000000E+00
	2	5.00E+00	4.55017929E-04	99926	2.93862924E-01	7.06137076E-01	7.40000000E-04
	3	2.00E+00	1.96649242E-04	3	1.17532573E-01	8.82467427E-01	9.99970000E-01
	4	1.02E-02	1.11731235E-03	0	6.02369610E-04	9.99397630E-01	1.00000000E+00
26 cu	1	1.00E+01	5.21210721E-04	100000	5.87985955E-01	4.12014045E-01	0.00000000E+00
	2	4.99E+00	4.98732785E-04	99909	2.93810488E-01	7.06189512E-01	9.10000000E-04
	3	2.00E+00	2.16560964E-04	8	1.17507167E-01	8.82492833E-01	9.99920000E-01
	4	1.18E-02	1.16996805E-03	0	6.36389786E-04	9.99303610E-01	1.00000000E+00
27 cu	1	1.00E+01	4.75630950E-04	100000	5.88014334E-01	4.11985666E-01	0.00000000E+00
	2	5.00E+00	4.29121981E-04	99935	2.93888084E-01	7.06111916E-01	6.50000000E-04
	3	2.00E+00	1.38559198E-04	3	1.17541548E-01	8.82458452E-01	9.99970000E-01
	4	8.94E-03	1.02762587E-03	0	5.26034042E-04	9.99473966E-01	1.00000000E+00
28 cu	1	1.00E+01	4.43465920E-04	100000	5.88050908E-01	4.11949092E-01	0.00000000E+00
	2	5.00E+00	4.37062263E-04	99930	2.93882450E-01	7.06117550E-01	7.00000000E-04
	3	2.00E+00	1.93187792E-04	4	1.17536677E-01	8.82463323E-01	9.99960000E-01
	4	9.01E-03	1.01156393E-03	0	5.29964933E-04	9.99470035E-01	1.00000000E+00
29 cu	1	1.00E+01	5.94825135E-04	100000	5.87948051E-01	4.12051949E-01	0.00000000E+00
	2	4.99E+00	4.93906380E-04	99915	2.93816332E-01	7.06183668E-01	8.50000000E-04
	3	2.00E+00	2.14829633E-04	9	1.17509606E-01	8.82490394E-01	9.99910000E-01
	4	1.23E-02	1.23752863E-03	0	7.26010899E-04	9.99273989E-01	1.00000000E+00
30 cu	1	1.00E+01	4.62941069E-04	100000	5.88031945E-01	4.11968055E-01	0.00000000E+00
	2	5.00E+00	4.44521749E-04	99928	2.93875219E-01	7.06124781E-01	7.20000000E-04
	3	2.00E+00	1.94629873E-04	3	1.17535042E-01	8.82464958E-01	9.99970000E-01
	4	9.48E-03	1.04787550E-03	0	5.57793478E-04	9.99442207E-01	1.00000000E+00
37 cu	1	1.00E+01	4.67639853E-04	100000	5.88049711E-01	4.11950289E-01	0.00000000E+00
	2	5.00E+00	4.13806963E-04	99937	2.93906512E-01	7.06093488E-01	6.30000000E-04
	3	2.00E+00	1.81755604E-04	7	1.17548908E-01	8.82451092E-01	9.99930000E-01
	4	8.41E-03	1.00387621E-03	0	4.94869753E-04	9.99505130E-01	1.00000000E+00
38 cu	1	1.00E+01	4.61499818E-04	100000	5.88048619E-01	4.11951381E-01	0.00000000E+00
	2	5.00E+00	4.16344730E-04	99938	2.93902794E-01	7.06097206E-01	6.20000000E-04
	3	2.00E+00	1.86370511E-04	3	1.17544072E-01	8.82455928E-01	9.99970000E-01
	4	8.58E-03	1.00547215E-03	0	5.04514342E-04	9.99495486E-01	1.00000000E+00
39 cu	1	1.00E+01	4.85930970E-04	100000	5.88021231E-01	4.11978769E-01	0.00000000E+00
	2	5.00E+00	4.69329418E-04	99920	2.93845447E-01	7.06154553E-01	8.00000000E-04
	3	2.00E+00	2.08435522E-04	7	1.17517854E-01	8.82482146E-01	9.99930000E-01
	4	1.05E-02	1.09257072E-03	0	6.15468109E-04	9.99384532E-01	1.00000000E+00
40 cu	1	1.00E+01	5.36478939E-04	100000	5.87996405E-01	4.12003595E-01	0.00000000E+00
	2	5.00E+00	4.55569534E-04	99925	2.93859387E-01	7.06140613E-01	7.50000000E-04
	3	2.00E+00	2.06813129E-04	7	1.17519804E-01	8.82480196E-01	9.99930000E-01
	4	1.06E-02	1.13206729E-03	0	6.24404150E-04	9.99375596E-01	1.00000000E+00

41 cu	1	1.00E+01	5.71009819E-04	100000	5.87967012E-01	4.12032988E-01	0.00000000E+00
	2	5.00E+00	4.67061269E-04	99923	2.93845110E-01	7.06154890E-01	7.70000000E-04
	3	2.00E+00	2.06372832E-04	4	1.17520606E-01	8.82479394E-01	9.99960000E-01
	4	1.13E-02	1.18735316E-03	0	6.67272201E-04	9.99332728E-01	1.00000000E+00
42 cu	1	1.00E+01	5.58479398E-04	100000	5.87981321E-01	4.12018679E-01	0.00000000E+00
	2	5.00E+00	4.53666580E-04	99926	2.93864159E-01	7.06135841E-01	7.40000000E-04
	3	2.00E+00	2.02050855E-04	8	1.17525080E-01	8.82474920E-01	9.99920000E-01
	4	1.07E-02	1.15526386E-03	0	6.29439898E-04	9.99370560E-01	1.00000000E+00
43 cu	1	1.00E+01	5.10087062E-04	100000	5.88007899E-01	4.11992101E-01	0.00000000E+00
	2	5.00E+00	4.55302623E-04	99927	2.93862726E-01	7.06137274E-01	7.30000000E-04
	3	2.00E+00	2.02237963E-04	6	1.17525523E-01	8.82474477E-01	9.99940000E-01
	4	1.03E-02	1.10555941E-03	0	6.03851958E-04	9.99396148E-01	1.00000000E+00
50 cu	1	1.00E+01	5.71252720E-04	100000	5.87951347E-01	4.12048653E-01	0.00000000E+00
	2	4.99E+00	4.98271023E-04	99909	2.93809486E-01	7.06190514E-01	9.10000000E-04
	3	2.00E+00	2.23728726E-04	5	1.17498623E-01	8.82501377E-01	9.99950000E-01
	4	1.26E-02	1.22840854E-03	0	7.40543537E-04	9.99259456E-01	1.00000000E+00
51 cu	1	1.00E+01	5.27714205E-04	100000	5.87993057E-01	4.12006943E-01	0.00000000E+00
	2	5.00E+00	4.79657174E-04	99922	2.93829274E-01	7.06170726E-01	7.80000000E-04
	3	2.00E+00	2.11558669E-04	1	1.17515134E-01	8.82484866E-01	9.99990000E-01
	4	1.13E-02	1.15113868E-03	0	6.62534960E-04	9.99337465E-01	1.00000000E+00
52 cu	1	1.00E+01	5.51331381E-04	100000	5.87962503E-01	4.12037497E-01	0.00000000E+00
	2	4.99E+00	5.07737568E-04	99905	2.93799582E-01	7.06200418E-01	9.50000000E-04
	3	2.00E+00	2.22948744E-04	5	1.17499494E-01	8.82500506E-01	9.99950000E-01
	4	1.26E-02	1.21490413E-03	0	7.38421389E-04	9.99261579E-01	1.00000000E+00
53 cu	1	1.00E+01	5.34153776E-04	100000	5.87984409E-01	4.12015591E-01	0.00000000E+00
	2	4.99E+00	4.91485873E-04	99911	2.93821765E-01	7.06178235E-01	8.90000000E-04
	3	2.00E+00	2.13199426E-04	3	1.17512637E-01	8.82487363E-01	9.99970000E-01
	4	1.16E-02	1.17037806E-03	0	6.81188586E-04	9.99318811E-01	1.00000000E+00
54 cu	1	1.00E+01	4.92935244E-04	100000	5.88017913E-01	4.11982087E-01	0.00000000E+00
	2	5.00E+00	4.68461454E-04	99921	2.93846901E-01	7.06153099E-01	7.90000000E-04
	3	2.00E+00	2.04058510E-04	4	1.17523646E-01	8.82476354E-01	9.99960000E-01
	4	1.04E-02	1.09766459E-03	0	6.11539771E-04	9.99388460E-01	1.00000000E+00
55 cu	1	1.00E+01	5.15477615E-04	100000	5.88006560E-01	4.11993440E-01	0.00000000E+00
	2	5.00E+00	4.52714361E-04	99930	2.93860681E-01	7.06139319E-01	7.00000000E-04
	3	2.00E+00	2.05400545E-04	9	1.17520884E-01	8.82479116E-01	9.99910000E-01
	4	1.04E-02	1.10963371E-03	0	6.11874610E-04	9.99388125E-01	1.00000000E+00
56 cu	1	1.00E+01	4.88215330E-04	100000	5.88012098E-01	4.11987902E-01	0.00000000E+00
	2	5.00E+00	4.84166630E-04	99914	2.93833358E-01	7.06166642E-01	8.60000000E-04
	3	2.00E+00	2.03074174E-04	4	1.17524901E-01	8.82475099E-01	9.99960000E-01
	4	1.07E-02	1.11256831E-03	0	6.29642441E-04	9.99370358E-01	1.00000000E+00
65 gt	1	0.00E+00	0.00000000E+00	0	0.00000000E+00	1.00000000E+00	1.00000000E+00
	2	1.70E+01	0.00000000E+00	0	1.00000000E+00	0.00000000E+00	1.00000000E+00
66 gt	1	4.40E-07	4.40290165E-07	0	2.58995505E-08	9.99999974E-01	1.00000000E+00
	2	1.70E+01	4.40290194E-07	1	9.99999974E-01	2.58995505E-08	9.99990000E-01
67 gt	1	1.70E+01	0.00000000E+00	0	1.00000000E+00	0.00000000E+00	1.00000000E+00
	2	0.00E+00	0.00000000E+00	0	0.00000000E+00	1.00000000E+00	1.00000000E+00

70 gt	1	1.70E+01	0.00000000E+00	0	1.00000000E+00	0.00000000E+00	1.00000000E+00
	2	0.00E+00	0.00000000E+00	0	0.00000000E+00	1.00000000E+00	1.00000000E+00

PRIMITIVE NO NAME	TRANS. FR	TO	TOTAL NO OCCURNCS	NON-ZERO RUNS	MEAN TIME BETW TRNS	RELIABILITY	UNRELIABILITY
2 au	1	4	104	104	1.63E+04	9.98960000E-01	1.04000000E-03
	1	2	99896	99896	1.70E+01	1.04000000E-03	9.98960000E-01
	2	4	93	93	1.83E+04	9.99070000E-01	9.30000000E-04
	2	3	99803	9980	1.70E+01	1.97000000E-03	9.98030000E-01
	3	4	18	18	9.44E+04	9.99820000E-01	1.80000000E-04
3 au	1	4	97	97	1.75E+04	9.99030000E-01	9.70000000E-04
	1	2	99903	99903	1.70E+01	9.70000000E-04	9.99030000E-01
	2	4	104	104	1.63E+04	9.98960000E-01	1.04000000E-03
	2	3	99799	99799	1.70E+01	2.01000000E-03	9.97990000E-01
	3	4	11	11	1.55E+05	9.99890000E-01	1.10000000E-04
4 au	1	4	102	102	1.67E+04	9.98980000E-01	1.02000000E-03
	1	2	99898	99898	1.70E+01	1.02000000E-03	9.98980000E-01
	2	4	99	99	1.72E+04	9.99010000E-01	9.90000000E-04
	2	3	99799	99799	1.70E+01	2.01000000E-03	9.97990000E-01
	3	4	12	12	1.42E+05	9.99880000E-01	1.20000000E-04
5 au	1	4	114	114	1.49E+04	9.98860000E-01	1.14000000E-03
	1	2	99886	99886	1.70E+01	1.14000000E-03	9.98860000E-01
	2	4	89	89	1.91E+04	9.99110000E-01	8.90000000E-04
	2	3	99797	99797	1.70E+01	2.03000000E-03	9.97970000E-01
	3	4	18	18	9.44E+04	9.99820000E-01	1.80000000E-04
6 au	1	4	103	103	1.65E+04	9.98970000E-01	1.03000000E-03
	1	2	99897	99897	1.70E+01	1.03000000E-03	9.98970000E-01
	2	4	81	81	2.10E+04	9.99190000E-01	8.10000000E-04
	2	3	99816	99816	1.70E+01	1.84000000E-03	9.98160000E-01
	3	4	10	10	1.70E+05	9.99900000E-01	1.00000000E-04
11 tts	1	2	0	0	1.70E+01	1.00000000E+00	0.00000000E+00
12 bu	1	4	55	55	3.09E+04	9.99450000E-01	5.50000000E-04
	1	2	99945	99945	1.70E+01	5.50000000E-04	9.99450000E-01
	2	4	12	12	1.42E+05	9.99880000E-01	1.20000000E-04
	2	3	99933	99933	1.70E+01	6.70000000E-04	9.99330000E-01
	3	4	21	21	8.10E+04	9.99790000E-01	2.10000000E-04
13 bu	1	4	50	50	3.40E+04	9.99500000E-01	5.00000000E-04
	1	2	99950	99950	1.70E+01	5.00000000E-04	9.99500000E-01
	2	4	15	15	1.13E+05	9.99850000E-01	1.50000000E-04
	2	3	99935	99935	1.70E+01	6.50000000E-04	9.99350000E-01
	3	4	22	22	7.73E+04	9.99780000E-01	2.20000000E-04
14 bu	1	4	47	47	3.62E+04	9.99530000E-01	4.70000000E-04
	1	2	99953	99953	1.70E+01	4.70000000E-04	9.99530000E-01
	2	4	11	11	1.55E+05	9.99890000E-01	1.10000000E-04
	2	3	99942	99942	1.70E+01	5.80000000E-04	9.99420000E-01
	3	4	12	12	1.42E+05	9.99880000E-01	1.20000000E-04
15 bu	1	4	43	43	3.95E+04	9.99570000E-01	4.30000000E-04
	1	2	99957	99957	1.70E+01	4.30000000E-04	9.99570000E-01
	2	4	14	14	1.21E+05	9.99860000E-01	1.40000000E-04
	2	3	99943	99943	1.70E+01	5.70000000E-04	9.99430000E-01
	3	4	14	14	1.21E+05	9.99860000E-01	1.40000000E-04
16 bu	1	4	52	52	3.27E+04	9.99480000E-01	5.20000000E-04
	1	2	99948	99948	1.70E+01	5.20000000E-04	9.99480000E-01
	2	4	15	15	1.13E+05	9.99850000E-01	1.50000000E-04
	2	3	99933	99933	1.70E+01	6.70000000E-04	9.99330000E-01
	3	4	17	17	1.00E+05	9.99830000E-01	1.70000000E-04
17 bu	1	4	52	52	3.27E+04	9.99480000E-01	5.20000000E-04
	1	2	99948	99948	1.70E+01	5.20000000E-04	9.99480000E-01
	2	4	13	13	1.31E+05	9.99870000E-01	1.30000000E-04

	2	3	99935	99935	1.70E+01	6.50000000E-04	9.99350000E-01
	3	4	14	14	1.21E+05	9.99860000E-01	1.40000000E-04
23 tras	1	2	1	1	1.70E+06	9.99990000E-01	1.00000000E-05
24 cu	1	4	90	90	1.89E+04	9.99100000E-01	9.00000000E-04
	1	2	99910	99910	1.70E+01	9.00000000E-04	9.99100000E-01
	2	4	21	21	8.10E+04	9.99790000E-01	2.10000000E-04
	2	3	99889	99889	1.70E+01	1.11000000E-03	9.98890000E-01
	3	4	1	1	1.70E+06	9.99990000E-01	1.00000000E-05
25 cu	1	4	74	74	2.30E+04	9.99260000E-01	7.40000000E-04
	1	2	99926	99926	1.70E+01	7.40000000E-04	9.99260000E-01
	2	4	22	22	7.73E+04	9.99780000E-01	2.20000000E-04
	2	3	99904	99904	1.70E+01	9.60000000E-04	9.99040000E-01
	3	4	3	3	5.67E+05	9.99970000E-01	3.00000000E-05
26 cu	1	4	91	91	1.87E+04	9.99090000E-01	9.10000000E-04
	1	2	99909	99909	1.70E+01	9.10000000E-04	9.99090000E-01
	2	4	25	25	6.80E+04	9.99750000E-01	2.50000000E-04
	2	3	99884	99884	1.70E+01	1.16000000E-03	9.98840000E-01
	3	4	8	8	2.13E+05	9.99920000E-01	8.00000000E-05
27 cu	1	4	65	65	2.62E+04	9.99350000E-01	6.50000000E-04
	1	2	99935	99935	1.70E+01	6.50000000E-04	9.99350000E-01
	2	4	23	23	7.39E+04	9.99770000E-01	2.30000000E-04
	2	3	99912	99912	1.70E+01	8.80000000E-04	9.99120000E-01
	3	4	3	3	5.67E+05	9.99970000E-01	3.00000000E-05
28 cu	1	4	70	70	2.43E+04	9.99300000E-01	7.00000000E-04
	1	2	99930	99930	1.70E+01	7.00000000E-04	9.99300000E-01
	2	4	21	21	8.10E+04	9.99790000E-01	2.10000000E-04
	2	3	99909	99909	1.70E+01	9.10000000E-04	9.99090000E-01
	3	4	4	4	4.25E+05	9.99960000E-01	4.00000000E-05
29 cu	1	4	85	85	2.00E+04	9.99150000E-01	8.50000000E-04
	1	2	99915	99915	1.70E+01	8.50000000E-04	9.99150000E-01
	2	4	27	27	6.30E+04	9.99730000E-01	2.70000000E-04
	2	3	99888	99888	1.70E+01	1.12000000E-03	9.98880000E-01
	3	4	9	9	1.89E+05	9.99910000E-01	9.00000000E-05
30 cu	1	4	72	72	2.36E+04	9.99280000E-01	7.20000000E-04
	1	2	99928	99928	1.70E+01	7.20000000E-04	9.99280000E-01
	2	4	22	22	7.73E+04	9.99780000E-01	2.20000000E-04
	2	3	99906	99906	1.70E+01	9.40000000E-04	9.99060000E-01
	3	4	3	3	5.67E+05	9.99970000E-01	3.00000000E-05
37 cu	1	4	63	63	2.70E+04	9.99370000E-01	6.30000000E-04
	1	2	99937	99937	1.70E+01	6.30000000E-04	9.99370000E-01
	2	4	18	18	9.44E+04	9.99820000E-01	1.80000000E-04
	2	3	99919	99919	1.70E+01	8.10000000E-04	9.99190000E-01
	3	4	7	7	2.43E+05	9.99930000E-01	7.00000000E-05
38 cu	1	4	62	62	2.74E+04	9.99380000E-01	6.20000000E-04
	1	2	99938	99938	1.70E+01	6.20000000E-04	9.99380000E-01
	2	4	24	24	7.08E+04	9.99760000E-01	2.40000000E-04
	2	3	99914	99914	1.70E+01	8.60000000E-04	9.99140000E-01
	3	4	3	3	5.67E+05	9.99970000E-01	3.00000000E-05
39 cu	1	4	80	80	2.13E+04	9.99200000E-01	8.00000000E-04
	1	2	99920	99920	1.70E+01	8.00000000E-04	9.99200000E-01
	2	4	26	26	6.54E+04	9.99740000E-01	2.60000000E-04
	2	3	99894	99894	1.70E+01	1.06000000E-03	9.98940000E-01
	3	4	7	7	2.43E+05	9.99930000E-01	7.00000000E-05
40 cu	1	4	75	75	2.27E+04	9.99250000E-01	7.50000000E-04
	1	2	99925	99925	1.70E+01	7.50000000E-04	9.99250000E-01
	2	4	29	29	5.86E+04	9.99710000E-01	2.90000000E-04
	2	3	99896	99896	1.70E+01	1.04000000E-03	9.98960000E-01
	3	4	7	7	2.43E+05	9.99930000E-01	7.00000000E-05
41 cu	1	4	77	77	2.21E+04	9.99230000E-01	7.70000000E-04
	1	2	99923	99923	1.70E+01	7.70000000E-04	9.99230000E-01

	2	4	28	28	6.07E+04	9.99720000E-01	2.80000000E-04
	2	3	99895	99895	1.70E+01	1.05000000E-03	9.98950000E-01
	3	4	4	4	4.25E+05	9.99960000E-01	4.00000000E-05
42 cu	1	4	74	74	2.30E+04	9.99260000E-01	7.40000000E-04
	1	2	99926	99926	1.70E+01	7.40000000E-04	9.99260000E-01
	2	4	25	25	6.80E+04	9.99750000E-01	2.50000000E-04
	2	3	99901	99901	1.70E+01	9.90000000E-04	9.99010000E-01
	3	4	8	8	2.13E+05	9.99920000E-01	8.00000000E-05
43 cu	1	4	73	73	2.33E+04	9.99270000E-01	7.30000000E-04
	1	2	99927	99927	1.70E+01	7.30000000E-04	9.99270000E-01
	2	4	27	27	6.30E+04	9.99730000E-01	2.70000000E-04
	2	3	99900	99900	1.70E+01	1.00000000E-03	9.99000000E-01
	3	4	6	6	2.83E+05	9.99940000E-01	6.00000000E-05
50 cu	1	4	91	91	1.87E+04	9.99090000E-01	9.10000000E-04
	1	2	99909	99909	1.70E+01	9.10000000E-04	9.99090000E-01
	2	4	32	32	5.31E+04	9.99680000E-01	3.20000000E-04
	2	3	99877	99877	1.70E+01	1.23000000E-03	9.98770000E-01
	3	4	5	5	3.40E+05	9.99950000E-01	5.00000000E-05
51 cu	1	4	78	78	2.18E+04	9.99220000E-01	7.80000000E-04
	1	2	99922	99922	1.70E+01	7.80000000E-04	9.99220000E-01
	2	4	34	34	5.00E+04	9.99660000E-01	3.40000000E-04
	2	3	99888	99888	1.70E+01	1.12000000E-03	9.98880000E-01
	3	4	1	1	1.70E+06	9.99990000E-01	1.00000000E-05
52 cu	1	4	95	95	2.79E+04	9.99050000E-01	9.50000000E-04
	1	2	99905	99905	1.70E+01	9.50000000E-04	9.99050000E-01
	2	4	27	27	6.30E+04	9.99730000E-01	2.70000000E-04
	2	3	99878	99878	1.70E+01	1.22000000E-03	9.98780000E-01
	3	4	5	5	3.40E+05	9.99950000E-01	5.00000000E-05
53 cu	1	4	89	89	1.91E+04	9.99110000E-01	8.90000000E-04
	1	2	99911	99911	1.70E+01	8.90000000E-04	9.99110000E-01
	2	4	23	23	7.39E+04	9.99770000E-01	2.30000000E-04
	2	3	99888	99888	1.70E+01	1.12000000E-03	9.98880000E-01
	3	4	3	3	5.67E+05	9.99970000E-01	3.00000000E-05
54 cu	1	4	79	79	2.15E+04	9.99210000E-01	7.90000000E-04
	1	2	99921	99921	1.70E+01	7.90000000E-04	9.99210000E-01
	2	4	24	24	7.08E+04	9.99760000E-01	2.40000000E-04
	2	3	99897	99897	1.70E+01	1.03000000E-03	9.98970000E-01
	3	4	4	4	4.25E+05	9.99960000E-01	4.00000000E-05
55 cu	1	4	70	70	2.43E+04	9.99300000E-01	7.00000000E-04
	1	2	99930	99930	1.70E+01	7.00000000E-04	9.99300000E-01
	2	4	33	33	5.15E+04	9.99670000E-01	3.30000000E-04
	2	3	99897	99897	1.70E+01	1.03000000E-03	9.98970000E-01
	3	4	9	9	1.89E+05	9.99910000E-01	9.00000000E-05
56 cu	1	4	86	86	1.98E+04	9.99140000E-01	8.60000000E-04
	1	2	99914	99914	1.70E+01	8.60000000E-04	9.99140000E-01
	2	4	17	17	1.00E+05	9.99830000E-01	1.70000000E-04
	2	3	99897	99897	1.70E+01	1.03000000E-03	9.98970000E-01
	3	4	4	4	4.25E+05	9.99960000E-01	4.00000000E-05
65 gt	1	2	0	0	1.70E+01	1.00000000E+00	0.00000000E+00
	2	1	0	0	1.70E+01	1.00000000E+00	0.00000000E+00
66 gt	1	2	0	0	1.70E+01	1.00000000E+00	0.00000000E+00
	2	1	1	1	1.70E+06	9.99990000E-01	1.00000000E-05
67 gt	1	2	0	0	1.70E+01	1.00000000E+00	0.00000000E+00
	2	1	0	0	1.70E+01	1.00000000E+00	0.00000000E+00
70 gt	1	2	0	0	1.70E+01	1.00000000E+00	0.00000000E+00
	2	1	1	1	1.70E+06	$\boxed{9.99990000E-01}$	1.00000000E-05

System Reliability

SIMULATION RESULTS

Simulation name: M77
Number of simulation runs: 10000
Single run duration: 1000.000
Number of monitored primitives: 69
Random number seed: 12345

PRIMITIVE DESCR. NO NAME	TRANSITION TYPE	TRANSITION AND MODE DESCRIPTION FROM MODE(NO/NAME)	TO MODE(NO/NAME)
2 au	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
3 au	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
4 au	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
5 au	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
6 au	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
11 tcs	threshold	1 up	2 down
12 bu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
13 bu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
14 bu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
15 bu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
16 bu	failure	1 p1	4 fail
	control	1 p1	2 ph2

	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
17 bu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
23 trsa	threshold	1 up	2 down
24 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
25 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
26 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
27 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
28 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
29 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
30 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
37 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
38 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
39 cu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
40 cu	failure	1 p1	4 fail

	control	1 pl	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
41 cu	failure	1 pl	4 fail
	control	1 pl	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
42 cu	failure	1 pl	4 fail
	control	1 pl	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
43 cu	failure	1 pl	4 fail
	control	1 pl	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
50 cu	failure	1 pl	4 fail
	control	1 pl	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
51 cu	failure	1 pl	4 fail
	control	1 pl	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
52 cu	failure	1 pl	4 fail
	control	1 pl	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
53 cu	failure	1 pl	4 fail
	control	1 pl	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
54 cu	failure	1 pl	4 fail
	control	1 pl	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
55 cu	failure	1 pl	4 fail
	control	1 pl	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
56 cu	failure	1 pl	4 fail
	control	1 pl	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
65 gt	control	1 one	2 two
	control	2 two	1 one
66 gt	control	1 one	2 two
	control	2 two	1 one
67 gt	control	1 one	2 two
	control	2 two	1 one

70 gt		control	1 one			2 two		
		control	2 two			1 one		
PRIMITIVE NO NAME	MODE NO	AVERAGE TIME	STANDARD DEVIATION	NON-0 RUNS	AVAILABILITY	UNAVAILABILITY	RELIABILITY	
2 au	1	9.51E+02	1.77558637E+00	10000	3.16977937E-01	6.83022063E-01	0.00000000E+00	
	2	4.32E+02	1.60268784E+00	9065	1.44151064E-01	8.55848936E-01	9.35000000E-02	
	3	1.17E+03	5.96867514E+00	902	3.88615320E-01	6.11384680E-01	9.09800000E-01	
	4	4.51E+02	8.53116131E+00	0	1.50255679E-01	8.49744321E-01	1.00000000E+00	
3 au	1	9.52E+02	1.74372542E+00	10000	3.17276724E-01	6.82723276E-01	0.00000000E+00	
	2	4.31E+02	1.61769950E+00	9075	1.43620389E-01	8.56379611E-01	9.25000000E-02	
	3	1.16E+03	5.97712946E+00	870	3.88073489E-01	6.11926511E-01	9.13000000E-01	
	4	4.53E+02	8.53517151E+00	0	1.51029399E-01	8.48970601E-01	1.00000000E+00	
4 au	1	9.52E+02	1.74528766E+00	10000	3.17271114E-01	6.82728886E-01	0.00000000E+00	
	2	4.31E+02	1.61733520E+00	9067	1.43519381E-01	8.56480619E-01	9.33000000E-02	
	3	1.16E+03	6.02265358E+00	893	3.85955222E-01	6.14044778E-01	9.10700000E-01	
	4	4.60E+02	8.56289673E+00	0	1.53254285E-01	8.46745715E-01	1.00000000E+00	
5 au	1	9.51E+02	1.72826838E+00	10000	3.17069271E-01	6.82930729E-01	0.00000000E+00	
	2	4.30E+02	1.63278162E+00	9019	1.43338503E-01	8.56661497E-01	9.81000000E-02	
	3	1.17E+03	5.97096539E+00	842	3.88994355E-01	6.11005645E-01	9.15800000E-01	
	4	4.52E+02	8.55708313E+00	0	1.50597872E-01	8.49402128E-01	1.00000000E+00	
6 au	1	9.50E+02	1.77452266E+00	10000	3.16679716E-01	6.83320284E-01	0.00000000E+00	
	2	4.29E+02	1.63986421E+00	9021	1.43002420E-01	8.56997580E-01	9.79000000E-02	
	3	1.16E+03	6.01123238E+00	981	3.86624781E-01	6.13375219E-01	9.11900000E-01	
	4	4.61E+02	8.62078381E+00	0	1.53693084E-01	8.46306916E-01	1.00000000E+00	
11 tcs	1	3.00E+03	3.43019247E-01	21	9.99608475E-01	3.91524552E-04	9.97900000E-01	
	2	1.17E+00	3.43019247E-01	0	3.91524552E-04	9.99608475E-01	1.00000000E+00	
12 bu	1	9.74E+02	1.29741216E+00	10000	3.24700961E-01	6.75299039E-01	0.00000000E+00	
	2	4.70E+02	1.15671682E+00	9491	1.56727941E-01	8.43272059E-01	5.19000000E-02	
	3	1.32E+03	4.46414709E+00	1003	4.10157850E-01	5.59842150E-01	8.99200000E-01	
	4	2.35E+02	6.33235693E+00	0	7.84132488E-02	9.21586751E-01	1.00000000E+00	
13 bu	1	9.76E+02	1.23719442E+00	10000	3.25367604E-01	6.74632396E-01	0.00000000E+00	
	2	4.73E+02	1.10161652E+00	9527	1.57794125E-01	8.42205875E-01	4.73000000E-02	
	3	1.33E+03	4.29326820E+00	983	4.44780605E-01	5.55219395E-01	9.01700000E-01	
	4	2.16E+02	6.07615566E+00	0	7.20576662E-02	9.27942334E-01	1.00000000E+00	
14 bu	1	9.78E+02	1.18200004E+00	10000	3.26114556E-01	6.73885444E-01	0.00000000E+00	
	2	4.75E+02	1.06182504E+00	9561	1.58451673E-01	8.41548327E-01	4.39000000E-02	
	3	1.34E+03	4.17723703E+00	1013	4.47270358E-01	5.52729642E-01	8.98700000E-01	
	4	2.04E+02	5.87012053E+00	0	6.81634128E-02	9.31836587E-01	1.00000000E+00	
15 bu	1	9.77E+02	1.19976497E+00	10000	3.25748549E-01	6.74251451E-01	0.00000000E+00	
	2	4.74E+02	1.09890664E+00	9524	1.57836960E-01	8.42163040E-01	4.76000000E-02	
	3	1.34E+03	4.27147293E+00	1026	4.45128386E-01	5.54871614E-01	8.97400000E-01	
	4	2.14E+02	6.01657724E+00	0	7.12861059E-02	9.28713894E-01	1.00000000E+00	
16 bu	1	9.76E+02	1.24505591E+00	10000	3.25270375E-01	6.74729625E-01	0.00000000E+00	
	2	4.73E+02	1.10662282E+00	9521	1.57666837E-01	8.42333163E-01	4.79000000E-02	
	3	1.33E+03	4.29521179E+00	992	4.44562670E-01	5.55437330E-01	9.00800000E-01	
	4	2.18E+02	6.09637213E+00	0	7.25001179E-02	9.27499882E-01	1.00000000E+00	
17 bu	1	9.76E+02	1.25146997E+00	10000	3.25312395E-01	6.74687605E-01	0.00000000E+00	
	2	4.73E+02	1.10869944E+00	9519	1.57646088E-01	8.42353912E-01	4.81000000E-02	

	3	1.33E+03	4.32451868E+00	1044	4.43558822E-01	5.56441178E-01	8.95600000E-01
	4	2.20E+02	6.11383247E+00	0	7.34826965E-02	9.26517303E-01	1.00000000E+00
23 trsa	1	2.76E+03	5.41168928E+00	2476	9.20062745E-01	7.99372549E-02	7.52400000E-01
	2	2.40E+02	5.41168928E+00	0	7.99372551E-02	9.20062745E-01	1.00000000E+00
24 cu	1	9.62E+02	1.54415619E+00	10000	3.20744047E-01	6.79255953E-01	0.00000000E+00
	2	4.56E+02	1.37607050E+00	9249	1.52143301E-01	8.47856699E-01	7.51000000E-02
	3	1.33E+03	4.63609123E+00	341	4.42801277E-01	5.57198723E-01	9.65900000E-01
	4	2.53E+02	7.12944126E+00	0	8.43113762E-02	9.15688624E-01	1.00000000E+00
25 cu	1	9.64E+02	1.52982128E+00	10000	3.21170285E-01	6.78829715E-01	0.00000000E+00
	2	4.59E+02	1.34237897E+00	9294	1.52934296E-01	8.47065704E-01	7.06000000E-02
	3	1.34E+03	4.54069996E+00	316	4.45631350E-01	5.54368650E-01	9.68400000E-01
	4	2.41E+02	6.99143887E+00	0	8.02640702E-02	9.19735930E-01	1.00000000E+00
26 cu	1	9.62E+02	1.54186285E+00	10000	3.20826055E-01	6.79173945E-01	0.00000000E+00
	2	4.58E+02	1.35410321E+00	9266	1.52601893E-01	8.47398107E-01	7.34000000E-02
	3	1.33E+03	4.64057398E+00	358	4.42689871E-01	5.57310129E-01	9.64200000E-01
	4	2.52E+02	7.09613419E+00	0	8.38821819E-02	9.16117818E-01	1.00000000E+00
27 cu	1	9.64E+02	1.50045824E+00	10000	3.21360382E-01	6.78639618E-01	0.00000000E+00
	2	4.58E+02	1.34978831E+00	9283	1.52672561E-01	8.47327439E-01	7.17000000E-02
	3	1.33E+03	4.58795547E+00	320	4.44374200E-01	5.55625800E-01	9.68000000E-01
	4	2.45E+02	7.01308060E+00	0	8.15928579E-02	9.18407142E-01	1.00000000E+00
28 cu	1	9.64E+02	1.50240636E+00	10000	3.21313931E-01	6.78686069E-01	0.00000000E+00
	2	4.57E+02	1.36641634E+00	9262	1.52283159E-01	8.47716841E-01	7.38000000E-02
	3	1.33E+03	4.64934492E+00	309	4.42961[illegible]E-01	5.57038533E-01	9.69100000E-01
	4	2.50E+02	7.07723188E+00	0	8.34414437E-02	9.16558556E-01	1.00000000E+00
29 cu	1	9.61E+02	1.57503629E+00	10000	3.20434361E-01	6.79565639E-01	0.00000000E+00
	2	4.57E+02	1.36640370E+00	9250	1.52404421E-01	8.47595579E-01	7.50000000E-02
	3	1.33E+03	4.64031267E+00	320	4.43[illegible]E-01	5.56938183E-01	9.68000000E-01
	4	2.52E+02	7.14738512E+00	0	8.399[illegible]E-02	9.16000597E-01	1.00000000E+00
30 cu	1	[illegible]	1.52901268E+00	10000	3.21[illegible]E-01	6.78398338E-01	0.00000000E+00
	2	[illegible]	1.33844626E+00	9275	1.530[illegible]E-01	8.46963350E-01	7.25000000E-02
	3	[illegible]	4.54614353E+00	328	4.45[illegible]E-01	5.54701013E-01	9.67200000E-01
	4	[illegible]	7.00021267E+00	0	8.066[illegible]E-02	9.19337298E-01	1.00000000E+00
37 cu	1	9.63E+02	1.51815987E+00	10000	3.21038191E-01	6.78961809E-01	0.00000000E+00
	2	4.57E+02	1.36379790E+00	9252	1.52414965E-01	8.47585035E-01	7.48000000E-02
	3	1.33E+03	4.63058519E+00	346	4.42788739E-01	5.57211261E-01	9.65400000E-01
	4	2.51E+02	7.08085918E+00	0	8.37581052E-02	9.16241895E-01	1.00000000E+00
38 cu	1	9.64E+02	1.51316929E+00	10000	3.21464161E-01	6.78535839E-01	0.00000000E+00
	2	4.60E+02	1.32612658E+00	9303	1.53291809E-01	8.46708191E-01	6.97000000E-02
	3	1.34E+03	4.53194284E+00	340	4.45704608E-01	5.54295392E-01	9.66000000E-01
	4	2.39E+02	6.93644619E+00	0	7.95394224E-02	9.20460578E-01	1.00000000E+00
39 cu	1	9.64E+02	1.52026033E+00	10000	3.21253663E-01	6.78746337E-01	0.00000000E+00
	2	4.59E+02	1.33852327E+00	9295	1.53023301E-01	8.46976699E-01	7.05000000E-02
	3	1.33E+03	4.56026030E+00	360	4.44727940E-01	5.55272060E-01	9.64000000E-01
	4	2.43E+02	6.98695993E+00	0	8.09950966E-02	9.19004903E-01	1.00000000E+00
40 cu	1	9.65E+02	1.48422074E+00	10000	3.21674207E-01	6.78325793E-01	0.00000000E+00
	2	4.59E+02	1.33838379E+00	9291	1.52985469E-01	8.47014531E-01	7.09000000E-02
	3	1.33E+03	4.57161856E+00	361	4.44340888E-01	5.55659112E-01	9.63900000E-01
	4	2.43E+02	6.95500088E+00	0	8.09994368E-02	9.19000563E-01	1.00000000E+00

41 cu	1	9.64E+02	1.50600505E+00	10000	3.21364950E-01	6.78635050E-01	0.00000000E+00
	2	4.58E+02	1.35035825E+00	9273	1.52754730E-01	8.47245270E-01	7.27000000E-02
	3	1.33E+03	4.57102728E+00	365	4.44266975E-01	5.55733025E-01	9.63500000E-01
	4	2.45E+02	6.99804306E+00	0	8.16133455E-02	9.18386655E-01	1.00000000E+00
42 cu	1	9.62E+02	1.55389798E+00	10000	3.20792327E-01	6.79207673E-01	0.00000000E+00
	2	4.58E+02	1.35262680E+00	9269	1.52638046E-01	8.47361954E-01	7.31000000E-02
	3	1.33E+03	4.62230062E+00	378	4.42829360E-01	5.57170640E-01	9.62200000E-01
	4	2.51E+02	7.08759069E+00	0	8.37402682E-02	9.16259732E-01	1.00000000E+00
43 cu	1	9.63E+02	1.53779459E+00	10000	3.21007486E-01	6.78992514E-01	0.00000000E+00
	2	4.58E+02	1.35428834E+00	9272	1.52647866E-01	8.47352134E-01	7.28000000E-02
	3	1.33E+03	4.57632542E+00	314	4.44676674E-01	5.55323326E-01	9.68600000E-01
	4	2.45E+02	7.04379988E+00	0	8.16679736E-02	9.18332026E-01	1.00000000E+00
50 cu	1	9.63E+02	1.52369666E+00	10000	3.21125726E-01	6.78874274E-01	0.00000000E+00
	2	4.58E+02	1.34535730E+00	9285	1.52737323E-01	8.47262677E-01	7.15000000E-02
	3	1.33E+03	4.58856916E+00	370	4.43609988E-01	5.56390012E-01	9.63000000E-01
	4	2.48E+02	7.02944613E+00	0	8.25269623E-02	9.17473038E-01	1.00000000E+00
51 cu	1	9.63E+02	1.53856766E+00	10000	3.20868697E-01	6.79131303E-01	0.00000000E+00
	2	4.57E+02	1.36975968E+00	9249	1.52287900E-01	8.47712100E-01	7.51000000E-02
	3	1.33E+03	4.64062977E+00	338	4.42864675E-01	5.57135325E-01	9.66200000E-01
	4	2.52E+02	7.11294935E+00	0	8.39787280E-02	9.16021272E-01	1.00000000E+00
52 cu	1	9.65E+02	1.49236433E+00	10000	3.21742980E-01	6.78257020E-01	0.00000000E+00
	2	4.60E+02	[illegible]	9314	1.53386153E-01	8.46613847E-01	6.96000000E-02
	3	1.34E+03	[illegible]	314	4.46513151E-01	[illegible]	9.63600000E-01
	4	2.35E+02	[illegible]	0	7.83577170E-02	[illegible]	1.00000000E+00
53 cu	1	9.62E+02	[illegible]	10000	3.20634408E-01	6.79365592E-01	0.00000000E+00
	2	4.57E+02	[illegible]	9264	1.52353085E-01	8.47646915E-01	7.36000000E-02
	3	1.33E+03	[illegible]	332	4.43061122E-01	5.56938878E-01	9.66800000E-01
	4	2.52E+02	[illegible]	0	8.39513853E-02	9.16048615E-01	1.00000000E+00
54 cu	1	9.63E+02	[illegible]	10000	3.20990934E-01	[illegible]	0.00000000E+00
	2	4.57E+02	[illegible]	9263	1.52474097E-01	8.47525903E-01	7.37000000E-02
	3	1.33E+03	[illegible]	308	4.44311224E-01	5.55688776E-01	9.69200000E-01
	4	2.47E+02	[illegible]	0	8.22236952E-02	9.17776305E-01	1.00000000E+00
55 cu	1	9.65E+02	[illegible]	10000	3.21613644E-01	6.78386356E-01	0.00000000E+00
	2	4.60E+02	[illegible]	9305	1.53187888E-01	8.46812112E-01	6.95000000E-02
	3	1.34E+03	4.54451370E+00	362	4.45136344E-01	5.54863656E-01	9.63800000E-01
	4	2.40E+02	6.93558884E+00	0	8.00621248E-02	9.19937875E-01	1.00000000E+00
56 cu	1	9.64E+02	1.51167059E+00	10000	3.21172813E-01	6.78827187E-01	0.00000000E+00
	2	4.58E+02	1.35528696E+00	9271	1.52683783E-01	8.47316217E-01	7.29000000E-02
	3	1.33E+03	4.56572485E+00	325	4.44788207E-01	5.55211793E-01	9.67500000E-01
	4	2.44E+02	7.01717758E+00	0	8.13551973E-02	9.18644803E-01	1.00000000E+00
65 gt	1	1.17E+00	3.43019247E-01	0	3.91524552E-04	9.99608475E-01	1.00000000E+00
	2	3.00E+03	3.43019247E-01	21	9.99608475E-01	3.91524552E-04	9.97900000E-01
66 gt	1	2.40E+02	5.41168928E+00	0	7.99372551E-02	9.20062745E-01	1.00000000E+00
	2	3.76E+03	5.41168928E+00	2476	9.20062745E-01	7.99372549E-02	7.52400000E-01
67 gt	1	0.00E+00	0.00000000E+00	0	0.00000000E+00	1.00000000E+00	1.00000000E+00
	2	3.00E+03	0.00000000E+00	0	1.00000000E+00	0.00000000E+00	1.00000000E+00

70 gt	1	2.41E+02	5.41592741E+00	0	8.023415543E-02	9.19765446E-01	1.00000000E+00
	2	2.76E+03	5.41592741E+00	2492	9.19765846E-01	8.023415418E-02	7.50800000E-01

PRIMITIVE NO NAME	TRANS. FR	TO	TOTAL NO OCCURNCS	NON-ZERO RUNS	MEAN TIME BETW TRNS	RELIABILITY	UNRELIABILITY
2 au	1	4	935	935	3.21E+04	9.06500000E-01	9.35000000E-02
	1	2	9065	9065	3.31E+03	9.35000000E-02	9.06500000E-01
	2	4	824	824	3.64E+04	9.17600000E-01	8.24000000E-02
	2	3	8241	8241	3.64E+03	1.75900000E-01	8.24100000E-01
	3	4	902	902	3.33E+04	9.09800000E-01	9.02000000E-02
3 au	1	4	925	925	3.24E+04	9.07500000E-01	9.25000000E-02
	1	2	9075	9075	3.31E+03	9.25000000E-02	9.07500000E-01
	2	4	866	866	3.46E+04	9.13400000E-01	8.66000000E-02
	2	3	8209	8209	3.65E+03	1.79100000E-01	8.20900000E-01
	3	4	870	870	3.45E+04	9.13000000E-01	8.70000000E-02
4 au	1	4	933	933	3.22E+04	9.06700000E-01	9.33000000E-02
	1	2	9067	9067	3.31E+03	9.33000000E-02	9.06700000E-01
	2	4	899	899	3.34E+04	9.10100000E-01	8.99000000E-02
	2	3	8168	8168	3.67E+03	1.83200000E-01	8.16800000E-01
	3	4	893	893	3.36E+04	9.10700000E-01	8.93000000E-02
5 au	1	4	981	981	3.06E+04	9.01900000E-01	9.81000000E-02
	1	2	9019	9019	3.33E+03	9.81000000E-02	9.01900000E-01
	2	4	817	817	3.67E+04	9.18300000E-01	8.17000000E-02
	2	3	8202	8202	3.66E+03	1.79800000E-01	8.20200000E-01
	3	4	842	842	3.56E+04	9.15800000E-01	8.42000000E-02
6 au	1	4	979	979	3.06E+04	9.02100000E-01	9.79000000E-02
	1	2	9021	9021	3.33E+03	9.79000000E-02	9.02100000E-01
	2	4	855	855	3.51E+04	9.14500000E-01	8.55000000E-02
	2	3	8166	8166	3.67E+03	1.83400000E-01	8.16600000E-01
	3	4	881	881	3.41E+04	9.11900000E-01	8.81000000E-02
11 trs	1	2	21	21	1.43E+06	9.97900000E-01	2.10000000E-03
12 bu	1	4	519	519	5.78E+04	9.48100000E-01	5.19000000E-02
	1	2	9481	9481	3.16E+03	5.19000000E-02	9.48100000E-01
	2	4	146	146	2.05E+05	9.85400000E-01	1.46000000E-02
	2	3	9335	9335	3.21E+03	6.65000000E-02	9.33500000E-01
	3	4	1008	1008	2.98E+04	8.99200000E-01	1.00800000E-01
13 bu	1	4	473	473	6.34E+04	9.52700000E-01	4.73000000E-02
	1	2	9527	9527	3.15E+03	4.73000000E-02	9.52700000E-01
	2	4	120	120	2.50E+05	9.88000000E-01	1.20000000E-02
	2	3	9407	9407	3.19E+03	5.93000000E-02	9.40700000E-01
	3	4	983	983	3.05E+04	9.01700000E-01	9.83000000E-02
14 bu	1	4	439	439	6.83E+04	9.56100000E-01	4.39000000E-02
	1	2	9561	9561	3.14E+03	4.39000000E-02	9.56100000E-01
	2	4	109	109	2.75E+05	9.89100000E-01	1.09000000E-02
	2	3	9452	9452	3.17E+03	5.48000000E-02	9.45200000E-01
	3	4	1013	1013	2.96E+04	8.98700000E-01	1.01300000E-01
15 bu	1	4	476	476	6.30E+04	9.52400000E-01	4.76000000E-02
	1	2	9524	9524	3.15E+03	4.76000000E-02	9.52400000E-01
	2	4	105	105	2.86E+05	9.89500000E-01	1.05000000E-02
	2	3	9419	9419	3.19E+03	5.81000000E-02	9.41900000E-01
	3	4	1026	1026	2.92E+04	8.97400000E-01	1.02600000E-01
16 bu	1	4	479	479	6.26E+04	9.52100000E-01	4.79000000E-02
	1	2	9521	9521	3.15E+03	4.79000000E-02	9.52100000E-01
	2	4	125	125	2.40E+05	9.87500000E-01	1.25000000E-02
	2	3	9396	9396	3.19E+03	6.04000000E-02	9.39600000E-01
	3	4	992	992	3.02E+04	9.00800000E-01	9.92000000E-02
17 bu	1	4	481	481	6.24E+04	9.51900000E-01	4.81000000E-02
	1	2	9519	9519	3.15E+03	4.81000000E-02	9.51900000E-01
	2	4	126	126	2.38E+05	9.87400000E-01	1.26000000E-02

	2	3	9393	9393	3.19E+03	6.07000000E-02	9.39300000E-01
	3	4	1044	1044	2.87E+04	8.95600000E-01	1.04400000E-01
23 trsa	1	2	2476	2476	1.21E+04	7.52400000E-01	2.47600000E-01
24 cu	1	4	751	751	3.99E+04	9.24900000E-01	7.51000000E-02
	1	2	9249	9249	3.24E+03	7.51000000E-02	9.24900000E-01
	2	4	226	226	1.33E+05	9.77400000E-01	2.26000000E-02
	2	3	9023	9023	3.32E+03	9.77000000E-02	9.02300000E-01
	3	4	341	341	8.80E+04	9.65900000E-01	3.41000000E-02
25 cu	1	4	706	706	4.25E+04	9.29400000E-01	7.06000000E-02
	1	2	9294	9294	3.23E+03	7.06000000E-02	9.29400000E-01
	2	4	229	229	1.31E+05	9.77100000E-01	2.29000000E-02
	2	3	9065	9065	3.31E+03	9.35000000E-02	9.06500000E-01
	3	4	316	316	9.49E+04	9.68400000E-01	3.16000000E-02
26 cu	1	4	734	734	4.09E+04	9.26600000E-01	7.34000000E-02
	1	2	9266	9266	3.24E+03	7.34000000E-02	9.26600000E-01
	2	4	229	229	1.31E+05	9.77100000E-01	2.29000000E-02
	2	3	9037	9037	3.32E+03	9.63000000E-02	9.03700000E-01
	3	4	358	358	8.38E+04	9.64200000E-01	3.58000000E-02
27 cu	1	4	717	717	4.18E+04	9.28300000E-01	7.17000000E-02
	1	2	9283	9283	3.23E+03	7.17000000E-02	9.28300000E-01
	2	4	238	238	1.26E+05	9.76200000E-01	2.38000000E-02
	2	3	9045	9045	3.32E+03	9.55000000E-02	9.04500000E-01
	3	4	320	320	9.38E+04	9.68000000E-01	3.20000000E-02
28 cu	1	4	738	738	4.07E+04	9.26200000E-01	7.38000000E-02
	1	2	9262	9262	3.24E+03	7.38000000E-02	9.26200000E-01
	2	4	245	245	1.22E+05	9.75500000E-01	2.45000000E-02
	2	3	9017	9017	3.33E+03	9.83000000E-02	9.01700000E-01
	3	4	309	309	9.71E+04	9.69100000E-01	3.09000000E-02
29 cu	1	4	750	750	4.00E+04	9.25000000E-01	7.50000000E-02
	1	2	9250	9250	3.24E+03	7.50000000E-02	9.25000000E-01
	2	4	222	222	1.35E+05	9.77800000E-01	2.22000000E-02
	2	3	9028	9028	3.32E+03	9.72000000E-02	9.02800000E-01
	3	4	320	320	9.38E+04	9.68000000E-01	3.20000000E-02
30 cu	1	4	725	725	4.14E+04	9.27500000E-01	7.25000000E-02
	1	2	9275	9275	3.23E+03	7.25000000E-02	9.27500000E-01
	2	4	202	202	1.49E+05	9.79800000E-01	2.02000000E-02
	2	3	9073	9073	3.31E+03	9.27000000E-02	9.07300000E-01
	3	4	328	328	9.15E+04	9.67200000E-01	3.28000000E-02
37 cu	1	4	748	748	4.01E+04	9.25200000E-01	7.48000000E-02
	1	2	9252	9252	3.24E+03	7.48000000E-02	9.25200000E-01
	2	4	225	225	1.33E+05	9.77500000E-01	2.25000000E-02
	2	3	9027	9027	3.32E+03	9.73000000E-02	9.02700000E-01
	3	4	346	346	8.67E+04	9.65400000E-01	3.46000000E-02
38 cu	1	4	697	697	4.30E+04	9.30300000E-01	6.97000000E-02
	1	2	9303	9303	3.22E+03	6.97000000E-02	9.30300000E-01
	2	4	213	213	1.41E+05	9.78700000E-01	2.13000000E-02
	2	3	9090	9090	3.30E+03	9.10000000E-02	9.09000000E-01
	3	4	340	340	8.82E+04	9.66000000E-01	3.40000000E-02
39 cu	1	4	705	705	4.26E+04	9.29500000E-01	7.05000000E-02
	1	2	9295	9295	3.23E+03	7.05000000E-02	9.29500000E-01
	2	4	222	222	1.35E+05	9.77800000E-01	2.22000000E-02
	2	3	9073	9073	3.31E+03	9.27000000E-02	9.07300000E-01
	3	4	360	360	8.33E+04	9.64000000E-01	3.60000000E-02
40 cu	1	4	709	709	4.23E+04	9.29100000E-01	7.09000000E-02
	1	2	9291	9291	3.23E+03	7.09000000E-02	9.29100000E-01
	2	4	217	217	1.38E+05	9.78300000E-01	2.17000000E-02
	2	3	9074	9074	3.31E+03	9.26000000E-02	9.07400000E-01
	3	4	361	361	8.31E+04	9.63900000E-01	3.61000000E-02
41 cu	1	4	727	727	4.13E+04	9.27300000E-01	7.27000000E-02
	1	2	9273	9273	3.24E+03	7.27000000E-02	9.27300000E-01

	2	4	210	210	1.43E+05	9.79000000E-01	2.10000000E-02
	2	3	9063	9063	3.31E+03	9.37000000E-02	9.06300000E-01
	3	4	365	365	8.22E+04	9.63500000E-01	3.65000000E-02
42 cu	1	4	731	731	4.10E+04	9.26900000E-01	7.31000000E-02
	1	2	9269	9269	3.24E+03	7.31000000E-02	9.26900000E-01
	2	4	226	226	1.33E+05	9.77400000E-01	2.26000000E-02
	2	3	9043	9043	3.32E+03	9.57000000E-02	9.04300000E-01
	3	4	378	378	7.94E+04	9.62200000E-01	3.78000000E-02
43 cu	1	4	728	728	4.12E+04	9.27200000E-01	7.28000000E-02
	1	2	9272	9272	3.24E+03	7.28000000E-02	9.27200000E-01
	2	4	221	221	1.36E+05	9.77900000E-01	2.21000000E-02
	2	3	9051	9051	3.31E+03	9.49000000E-02	9.05100000E-01
	3	4	314	314	9.55E+04	9.68600000E-01	3.14000000E-02
50 cu	1	4	715	715	4.20E+04	9.28500000E-01	7.15000000E-02
	1	2	9285	9285	3.23E+03	7.15000000E-02	9.28500000E-01
	2	4	235	235	1.28E+05	9.76500000E-01	2.35000000E-02
	2	3	9050	9050	3.31E+03	9.50000000E-02	9.05000000E-01
	3	4	370	370	8.11E+04	9.63000000E-01	3.70000000E-02
51 cu	1	4	751	751	3.99E+04	9.24900000E-01	7.51000000E-02
	1	2	9249	9249	3.24E+03	7.51000000E-02	9.24900000E-01
	2	4	220	220	1.36E+05	9.78000000E-01	2.20000000E-02
	2	3	9029	9029	3.32E+03	9.71000000E-02	9.02900000E-01
	3	4	338	338	8.88E+04	9.66200000E-01	3.38000000E-02
52 cu	1	4	686	686	4.37E+04	9.31400000E-01	6.86000000E-02
	1	2	9314	9314	3.22E+03	6.86000000E-02	9.31400000E-01
	2	4	218	218	1.38E+05	9.78200000E-01	2.18000000E-02
	2	3	9096	9096	3.30E+03	9.04000000E-02	9.09600000E-01
	3	4	314	314	9.55E+04	9.68600000E-01	3.14000000E-02
53 cu	1	4	736	736	4.08E+04	9.26400000E-01	7.36000000E-02
	1	2	9264	9264	3.24E+03	7.36000000E-02	9.26400000E-01
	2	4	237	237	1.27E+05	9.76300000E-01	2.37000000E-02
	2	3	9027	9027	3.32E+03	9.73000000E-02	9.02700000E-01
	3	4	332	332	9.04E+04	9.66800000E-01	3.32000000E-02
54 cu	1	4	737	737	4.07E+04	9.26300000E-01	7.37000000E-02
	1	2	9263	9263	3.24E+03	7.37000000E-02	9.26300000E-01
	2	4	227	227	1.32E+05	9.77300000E-01	2.27000000E-02
	2	3	9036	9036	3.32E+03	9.64000000E-02	9.03600000E-01
	3	4	308	308	9.74E+04	9.69200000E-01	3.08000000E-02
55 cu	1	4	695	695	4.32E+04	9.30500000E-01	6.95000000E-02
	1	2	9305	9305	3.22E+03	6.95000000E-02	9.30500000E-01
	2	4	220	220	1.36E+05	9.78000000E-01	2.20000000E-02
	2	3	9085	9085	3.30E+03	9.15000000E-02	9.08500000E-01
	3	4	362	362	8.29E+04	9.63800000E-01	3.62000000E-02
56 cu	1	4	729	729	4.12E+04	9.27100000E-01	7.29000000E-02
	1	2	9271	9271	3.24E+03	7.29000000E-02	9.27100000E-01
	2	4	217	217	1.38E+05	9.78300000E-01	2.17000000E-02
	2	3	9054	9054	3.31E+03	9.46000000E-02	9.05400000E-01
	3	4	325	325	9.23E+04	9.67500000E-01	3.25000000E-02
65 gt	1	2	0	0	3.00E+03	1.00000000E+00	0.00000000E+00
	2	1	$\boxed{21}$	21	1.43E+06	9.97900000E-01	2.10000000E-03
66 gt	1	2	0	0	3.00E+03	1.00000000E+00	0.00000000E+00
	2	1	$\boxed{2476}$	2476	1.21E+04	7.52400000E-01	2.47600000E-01
67 gt	1	2	0	0	3.00E+03	1.00000000E+00	0.00000000E+00
	2	1	$\boxed{0}$	0	3.00E+03	1.00000000E+00	0.00000000E+00
70 gt	1	2	0	0	3.00E+03	1.00000000E+00	0.00000000E+00
	2	1	2492	2492	1.20E+04	7.50800000E-01	2.49200000E-01

SIMULATION RESULTS

Simulation name: BUT
Number of simulation runs: 500000
Single run duration: 17.00000
Number of monitored primitives: 13
Random number seed: 12345

PRIMITIVE DESCR. NO NAME	TRANSITION TYPE	TRANSITION AND MODE DESCRIPTION FROM MODE NO NAME	TO MODE NO NAME)
2 bu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
3 bu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
4 bu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
5 bu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
6 bu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
7 bu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
13 trsa	threshold	1 up	2 down
14 gt	control	1 one	2 two
	control	2 two	1 one

PRIMITIVE NO NAME	MODE NO	AVERAGE TIME	STANDARD DEVIATION	NON-0 RUNS	AVAILABILITY	UNAVAILABILITY	RELIABILITY
2 bu	1	1.00E+01	1.76514281E-04	500000	5.88092249E-01	4.11907751E-01	0.00000000E+00
	2	5.00E+00	1.67690785E-04	499741	2.93946080E-01	7.06053920E-01	5.18000000E-04
	3	2.00E+00	7.45570651E-05	86	1.17561909E-01	8.82438091E-01	9.99828000E-01
	4	6.80E-03	3.95220966E-04	0	3.99762593E-04	9.99600237E-01	1.00000000E+00
3 bu	1	1.00E+01	1.92852051E-04	500000	5.88072600E-01	4.11927400E-01	0.00000000E+00
	2	5.00E+00	1.70275613E-04	499733	2.93940838E-01	7.06059162E-01	5.34000000E-04
	3	2.00E+00	7.53794156E-05	77	1.17560300E-01	8.82439700E-01	9.99846000E-01
	4	7.25E-03	4.16279683E-04	0	4.26261840E-04	9.99573738E-01	1.00000000E+00
4 bu	1	1.00E+01	1.83251715E-04	500000	5.88088959E-01	4.11911041E-01	0.00000000E+00
	2	5.00E+00	1.62309472E-04	499756	2.93957493E-01	7.06042507E-01	4.88000000E-04

	3	2.00E+00	7.24345955E-05	90	1.17566341E-01	8.82433659E-01	9.99820000E-01
	4	6.58E-03	3.95668176E-04	0	3.87207649E-04	9.99612792E-01	1.00000000E+00
5 bu	1	1.00E+01	1.81377764E-04	500000	5.88090459E-01	4.11909541E-01	0.00000000E+00
	2	5.00E+00	1.66262995E-04	499752	2.93945311E-01	7.06054689E-01	4.96000000E-04
	3	2.00E+00	7.61544434E-05	75	1.17558547E-01	8.82441453E-01	9.99850000E-01
	4	6.90E-03	3.98319709E-04	0	4.05682985E-04	9.99594317E-01	1.00000000E+00
6 bu	1	1.00E+01	1.82118878E-04	500000	5.88086096E-01	4.11913904E-01	0.00000000E+00
	2	5.00E+00	1.68140599E-04	499738	2.93945984E-01	7.06054016E-01	5.24000000E-04
	3	2.00E+00	7.42727570E-05	82	1.17562658E-01	8.82437342E-01	9.99836000E-01
	4	6.89E-03	4.01570258E-04	0	4.05262038E-04	9.99594738E-01	1.00000000E+00
7 bu	1	1.00E+01	1.74410467E-04	500000	5.88098351E-01	4.11901649E-01	0.00000000E+00
	2	5.00E+00	1.58435956E-04	499768	2.93963563E-01	7.06036437E-01	4.64000000E-04
	3	2.00E+00	7.06885912E-05	57	1.17571213E-01	8.82428787E-01	9.99886000E-01
	4	6.24E-03	3.82894854E-04	0	3.66873260E-04	9.99633127E-01	1.00000000E+00
13 trsa	1	1.70E+01	2.90046773E-05	7	9.99996341E-01	3.65930726E-06	9.99986000E-01
	2	6.22E-05	2.90046773E-05	0	3.65930726E-06	9.99996341E-01	1.00000000E+00
14 gt	1	6.22E-05	2.90046773E-05	0	3.65930726E-06	9.99996341E-01	1.00000000E+00
	2	1.70E+01	2.90046773E-05	7	9.99996341E-01	3.65930726E-06	9.99986000E-01

PRIMITIVE NO NAME	TRANS. FR	TO	TOTAL NO OCCURNCS	NON-ZERO RUNS	MEAN TIME BETW TRNS	RELIABILITY	UNRELIABILITY
2 bu	1	4	259	259	3.28E+04	9.99482000E-01	5.18000000E-04
	1	2	499741	499741	1.70E+01	5.18000000E-04	9.99482000E-01
	2	4	63	63	1.35E+05	9.99874000E-01	1.26000000E-04
	2	3	499678	499678	1.70E+01	6.44000000E-04	9.99356000E-01
	3	4	86	86	9.88E+04	9.99828000E-01	1.72000000E-04
3 bu	1	4	267	267	3.18E+04	9.99466000E-01	5.34000000E-04
	1	2	499733	499733	1.70E+01	5.34000000E-04	9.99466000E-01
	2	4	62	62	1.37E+05	9.99876000E-01	1.24000000E-04
	2	3	499671	499671	1.70E+01	6.58000000E-04	9.99342000E-01
	3	4	77	77	1.10E+05	9.99846000E-01	1.54000000E-04
4 bu	1	4	244	244	3.48E+04	9.99512000E-01	4.88000000E-04
	1	2	499756	499756	1.70E+01	4.88000000E-04	9.99512000E-01
	2	4	55	55	1.55E+05	9.99890000E-01	1.10000000E-04
	2	3	499701	499701	1.70E+01	5.98000000E-04	9.99402000E-01
	3	4	90	90	9.44E+04	9.99820000E-01	1.80000000E-04
5 bu	1	4	248	248	3.43E+04	9.99504000E-01	4.96000000E-04
	1	2	499752	499752	1.70E+01	4.96000000E-04	9.99504000E-01
	2	4	89	89	9.55E+04	9.99822000E-01	1.78000000E-04
	2	3	499663	499663	1.70E+01	6.74000000E-04	9.99326000E-01
	3	4	75	75	1.13E+05	9.99850000E-01	1.50000000E-04
6 bu	1	4	262	262	3.24E+04	9.99476000E-01	5.24000000E-04
	1	2	499738	499738	1.70E+01	5.24000000E-04	9.99476000E-01
	2	4	59	59	1.44E+05	9.99882000E-01	1.18000000E-04
	2	3	499679	499679	1.70E+01	6.42000000E-04	9.99358000E-01
	3	4	82	82	1.04E+05	9.99836000E-01	1.64000000E-04
7 bu	1	4	232	232	3.66E+04	9.99536000E-01	4.64000000E-04
	1	2	499768	499768	1.70E+01	4.64000000E-04	9.99536000E-01
	2	4	63	63	1.35E+05	9.99874000E-01	1.26000000E-04
	2	3	499705	499705	1.70E+01	5.90000000E-04	9.99410000E-01
	3	4	57	57	1.49E+05	9.99886000E-01	1.14000000E-04
13 trsa	1	2	7	7	1.21E+06	9.99986000E-01	1.40000000E-05
14 gt	1	2	0	0	1.70E+01	1.00000000E+00	0.00000000E+00
	2	1	7	7	1.21E+06	$\boxed{9.99986000E-01}$	1.40000000E-05

System Reliability

SIMULATION RESULTS

Simulation name: BUT
Number of simulation runs: 1000000
Single run duration: 10.00000
Number of monitored primitives: 13
Random number seed: 12345

PRIMITIVE DESCR. NO NAME	TRANSITION TYPE	TRANSITION AND MODE DESCRIPTION FROM MODE(NO/NAME)	TO MODE(NO/NAME)
2 bu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
3 bu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
4 bu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
5 bu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
6 bu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
7 bu	failure	1 p1	4 fail
	control	1 p1	2 ph2
	failure	2 ph2	4 fail
	control	2 ph2	3 ph3
	failure	3 ph3	4 fail
13 trsa	threshold	1 up	2 down
14 gt	control	1 one	2 two
	control	2 two	1 one

PRIMITIVE NO NAME	MODE NO	AVERAGE TIME	STANDARD DEVIATION	NON-0 RUNS	AVAILABILITY	UNAVAILABILITY	RELIABILITY
2 bu	1	1.00E+01	1.31102701E-04	499	9.99743365E-01	2.56635154E-04	9.99501000E-01
	2	0.00E+00	0.00000000E+00	0	0.00000000E+00	1.00000000E+00	1.00000000E+00
	3	0.00E+00	0.00000000E+00	0	0.00000000E+00	1.00000000E+00	1.00000000E+00
	4	2.57E-03	1.31102701E-04	0	2.56635156E-04	9.99743365E-01	1.00000000E+00
3 bu	1	1.00E+01	1.29692460E-04	512	9.99747403E-01	2.52597230E-04	9.99488000E-01
	2	0.00E+00	0.00000000E+00	0	0.00000000E+00	1.00000000E+00	1.00000000E+00
	3	0.00E+00	0.00000000E+00	0	0.00000000E+00	1.00000000E+00	1.00000000E+00
	4	2.53E-03	1.29692460E-04	0	2.52597231E-04	9.99747403E-01	1.00000000E+00
4 bu	1	1.00E+01	1.29913678E-04	514	9.99743718E-01	2.56281663E-04	9.99486000E-01
	2	0.00E+00	0.00000000E+00	0	0.00000000E+00	1.00000000E+00	1.00000000E+00

	3	0.00E+00	0.00000000E+00	0	0.00000000E+00	1.00000000E+00	1.00000000E+00
	4	2.56E-03	1.29913678E-04	0	2.56281665E-04	9.99743718E-01	1.00000000E+00
5 bu	1	1.00E+01	1.32352245E-04	508	9.99740104E-01	2.59896407E-04	9.99492000E-01
	2	0.00E+00	0.00000000E+00	0	0.00000000E+00	1.00000000E+00	1.00000000E+00
	3	0.00E+00	0.00000000E+00	0	0.00000000E+00	1.00000000E+00	1.00000000E+00
	4	2.60E-03	1.32352245E-04	0	2.59896409E-04	9.99740104E-01	1.00000000E+00
6 bu	1	1.00E+01	1.28915257E-04	484	9.99753099E-01	2.46901055E-04	9.99516000E-01
	2	0.00E+00	0.00000000E+00	0	0.00000000E+00	1.00000000E+00	1.00000000E+00
	3	0.00E+00	0.00000000E+00	0	0.00000000E+00	1.00000000E+00	1.00000000E+00
	4	2.47E-03	1.28915257E-04	0	2.46901056E-04	9.99753099E-01	1.00000000E+00
7 bu	1	1.00E+01	1.27863139E-04	519	9.99745932E-01	2.54068466E-04	9.99481000E-01
	2	0.00E+00	0.00000000E+00	0	0.00000000E+00	1.00000000E+00	1.00000000E+00
	3	0.00E+00	0.00000000E+00	0	0.00000000E+00	1.00000000E+00	1.00000000E+00
	4	2.54E-03	1.27863139E-04	0	2.54068468E-04	9.99745932E-01	1.00000000E+00
13 trsa	1	1.00E+01	6.70271584E-06	2	9.99999054E-01	9.46408415E-07	9.99998000E-01
	2	9.46E-06	6.70271584E-06	0	9.46408415E-07	9.99999054E-01	1.00000000E+00
14 gt	1	9.46E-06	6.70271584E-06	0	9.46408415E-07	9.99999054E-01	1.00000000E+00
	2	1.00E+01	6.70271584E-06	2	9.99999054E-01	9.46408415E-07	9.99998000E-01

PRIMITIVE NO NAME	TRANS. FR	TO	TOTAL NO OCCURNCS	NON-ZERO RUNS	MEAN TIME BETW TRNS	RELIABILITY	UNRELIABILITY
2 bu	1	4	499	499	2.00E+04	[illegible]	4.99000000E-04
	1	2	0	0	1.00E+01	1.00000000E+00	0.00000000E+00
	2	4	0	0	1.00E+01	1.00000000E+00	0.00000000E+00
	2	3	0	0	1.00E+01	1.00000000E+00	0.00000000E+00
	3	4	0	0	1.00E+01	1.00000000E+00	0.00000000E+00
3 bu	1	4	512	512	1.95E+04	[illegible]	5.12000000E-04
	1	2	0	0	1.00E+01	1.00000000E+00	0.00000000E+00
	2	4	0	0	1.00E+01	[illegible]	0.00000000E+00
	2	3	0	0	1.00E+01	1.00000000E+00	0.00000000E+00
	3	4	0	0	1.00E+01	1.00000000E+00	0.00000000E+00
4 bu	1	4	514	514	1.95E+04	9.99486000E-01	5.14000000E-04
	1	2	0	0	1.00E+01	1.00000000E+00	0.00000000E+00
	2	4	0	0	1.00E+01	1.00000000E+00	0.00000000E+00
	2	3	0	0	1.00E+01	1.00000000E+00	0.00000000E+00
	3	4	0	0	1.00E+01	1.00000000E+00	0.00000000E+00
5 bu	1	4	508	508	1.97E+04	9.99492000E-01	5.08000000E-04
	1	2	0	0	1.00E+01	1.00000000E+00	0.00000000E+00
	2	4	0	0	1.00E+01	1.00000000E+00	0.00000000E+00
	2	3	0	0	1.00E+01	1.00000000E+00	0.00000000E+00
	3	4	0	0	1.00E+01	1.00000000E+00	0.00000000E+00
6 bu	1	4	484	484	2.07E+04	9.99516000E-01	4.84000000E-04
	1	2	0	0	1.00E+01	1.00000000E+00	0.00000000E+00
	2	4	0	0	1.00E+01	1.00000000E+00	0.00000000E+00
	2	3	0	0	1.00E+01	1.00000000E+00	0.00000000E+00
	3	4	0	0	1.00E+01	1.00000000E+00	0.00000000E+00
7 bu	1	4	519	519	1.93E+04	9.99481000E-01	5.19000000E-04
	1	2	0	0	1.00E+01	1.00000000E+00	0.00000000E+00
	2	4	0	0	1.00E+01	1.00000000E+00	0.00000000E+00
	2	3	0	0	1.00E+01	1.00000000E+00	0.00000000E+00
	3	4	0	0	1.00E+01	1.00000000E+00	0.00000000E+00
13 trsa	1	2	2	2	5.00E+06	9.99998000E-01	2.00000000E-06
14 gt	1	2	0	0	1.00E+01	1.00000000E+00	0.00000000E+00
	2	1	2	2	5.00E+06	$\boxed{9.99998000E-01}$	2.00000000E-06

System Reliability

RADC/RBET 25
ATTN: Joseph A. Caroli
Griffiss AFB NY 13441-5700

Sanders Associates, Inc. 5
Software Systems Engineering
95 Canal Street
Nashua NH 03061

RADC/DOVL 1
Technical Library
Griffiss AFB NY 13441-5700

Administrator 5
Defense Technical Info Center
DTIC-FDA
Cameron Station Building 5
Alexandria VA 22304-6145

Strategic Defense Initiative Office 2
Office of the Secretary of Defense
Wash DC 20301-7100

RADC/RBE 1
ATTN: Mr. Anthony Feduccia
Griffiss AFB NY 13441

Reliability Analysis Center 1
PO Box 4700
Rome NY 13440-8200

AFCSA/SAMI 1
ATTN: Miss Griffin
10363 Pentagon
Washington DC 20330-5425

Naval Warfare Assessment Center 1
GIDEP Operations Center
ATTN: Mr. E. Richards
Code 30G1
Corona CA 91720

HQ AFSC/XTKT 1
Andrews AFB DC 20334-5000

DTESA/RQE ATTN: Mr. Larry G.McManus Kirtland AFB NM 87117-5000	1
HQ TAC/DOA Langley AFB VA 23665-5001	1
ASD/ENEMS Wright-Patterson AFB OH 45433-6503	2
ASD/ENSID ATTN: Mr. Eugene Wolanski Wright-Patterson AFB OH 45433	1
SM-ALC/MACEA ATTN: Danny McClure BLDG 250N McClellan AFB CA 95652	1
ASD/AFALC/AXAE ATTN: W. H. Dungey Wright-Patterson AFB OH 45433-6533	1
AFIT/LDEE Building 640, Area B Wright-Patterson AFB OH 45433-6583	1
WRDC/MLPO ATTN: G. H. Griffith Wright-Patterson AFB OH 45433-6533	1
WRDC/MLTE Wright-Patterson AFB OH 45433	1
Air Force Human Resources Lab Technical Documents Center AFHRL/LRS-TDC Wright-Patterson AFB OH 45433	1

2750 ABW/SSLT 1
Building 262
Post 11S
Wright-Patterson AFB OH 45433

AUL/LSE 1
Maxwell AFB AL 36112-5564

Defense Communications Engr Center 1
Technical Library
1860 Wiehle Avenue
Reston VA 22090-5500

US Army Strategic Defense Command 1
DASD-H-MPL
PO Box 1500
Huntsville AL 35807-3801

Chief of Naval Operations 1
OP-941F
Washington DC 20350-2000

Commanding Officer 1
Naval Avionics Center
Library
D/765
Indianapolis IN 46219-2189

Commanding Officer 1
Naval Training Systems Center
Technical Information Center
Building 2068
Orlando FL 32813-7100

Commanding Officer 1
Naval Ocean Systems Center
Technical Library
Code 9642B
San Diego CA 92152-5000

Commanding Officer 1
Naval Weapons Center
Technical Library
Code 3433
China Lake CA 93555-6001

Superintendent 1
Naval Post Graduate School
Code 1424
Monterey CA 93943-5000

Commanding Officer Naval Research Laboratory Code 2627 Washington DC 20375-5000	2
Commanding Officer US Army Missile Command Redstone Scientific Info Center AMSMI-RD-CS-R (Documents) Redstone Arsenal AL 35898-5241	2
Advisory Group on Electron Devices Technical Info Coordinator ATTN: Mr. John Hammond 201 Varick Street - Suite 1140 New York NY 10014	2
Los Alamos Scientific Laboratory Report Librarian ATTN: Mr. Dan Baca PO Box 1663, MS-P364 Los Alamos NM 87545	1
Rand Corporation Technical Library ATTN: Ms. Doris Helfer PO Box 2138 Santa Monica CA 90406-2138	1
AEDC Library Technical Reports File MS-100 Arnold AFS TN 37389-9998	1
Department of Transportation Library/10A Section M493.2 800 Independence Avenue S.W. Washington DC 20591	1
1839 EIG/EIEE Keesler AFB MS 39534-6348	1
AFEWC/ESRI San Antonio TX 78243-5000	3
ESD/XTP Hanscom AFB MA 01731-5000	1

ESD/AVSE 2
Building 1704
Hanscom AFB MA 01731-5000

Director 1
NSA/CSS
T513/TDL
ATTN: Mr. David Marjarum
Fort George G. Meade MD 20755-6000

Director 1
NSA/CSS R12
ATTN: Mr. Dennis Heinbuch
9800 Savage Road
Fort George G. Meade MD 20755-6000

Director 1
NSA/CSS
R5
Fort George G. Meade MD 20755-6000

Director 1
NSA/CSS
S21
Fort George G. Meade MD 20755-6000

Boeing Commercial Airplane Co. 1
ATTN: Mr. John Rose
MS7Y-21
PO Box 3707
Seattle WA 98124-2207

General Dynamics/Pomona Division 1
ATTN: E.M.Gilbert
PO Box 2507, M/Z 50-20
Pomona CA 91769-2507

General Dynamics - Convair Division 1
ATTN: John Philp
MZ 56-6010
PO Box 85357
San Diego CA 92138-5357

Hughes Aircraft Co. 1
ATTN: John G. Malcolm
Bldg 265/MSP53
8433 Fallbrook Ave.
Canoga Park CA 91304-3299

Lockheed Aeronautical Systems Co 1
ATTN: Mr. Dick Loveless
Bldg, 65-6
PO Box 551
Burbank, CA 91520-6643

Lockheed Missiles & Space Co. 1
ATTN: H.J. Frank
Mail Stop 0/62-95/Bldg. 564
PO Box 3504
Sunnyvale CA 94088-3504

McDonnell Douglas Missile Sys Co. 1
ATTN: J. J. McGarry
Dept E801 Mail Code 5981631
PO Box 516
St Louis MO 63166-0516

Sundstrand Corporation 1
ATTN: T.J. Doubek
4747 Harrison Ave
PO Box 7002, Dept 759-6
Rockford IL 61125

University of Southern California 1
ATTN: Professor Melvin A. Breuer
Electrical Eng. Dept. SAL 326
Los Angeles CA 90089-0781

Westinghouse Electric Corporation 1
ATTN: J.A. Gruessing
Electronic Systems Group
PO Box 746 MS5380
Baltimore MD 21203-0746

Westinghouse Electric Corporation 1
ATTN: Richard C. Banta
1111 Schilling Road, MS7062
Hunt Valley MD 21030

Evans Associates 1
804 Vickers Avenue
Durham NC 27701-3143

Boeing Electronics Company 1
ATTN: R.E. Tidbal
PO Box 3999, MS8A-83
Seattle, WA 98124-2207

Sandia Laboratories 1
ATTN: G.C. Novoyny
Division 7222
Albuquerque NM 87115

Eagle Technology Inc. 1
Attn: Mr. William Skewis
2300 South 9th Street
Arlington VA 22204-2301

McDonnell Douglas Astronautics Co. 1
ATTN: Dr. Hale
PO Box 516, E464/HQ/3N/1003202
St Louis MO 63166-0516

ITT Avionics Division 1
ATTN: C. Ehrenfried
100 Kingsland Road/Dept 73401
Clifton NJ 07014-1915

Motorola, Inc. 1
Attn:Mr. Allan Scholin
3501 Ed Bluestein Blvd
Austin, TX 78721

Honeywell Inc. 1
Attn: Avionics Library
1625 Zarthan Ave S., MN 15-2312
St. Louis Park, MN 55416-1499

Honeywell Avionics Division 1
Mail Station 229-1
13350 US Highway 19 S
Clearwater FL 33546-7920

Logical Technical Services Corp. 1
ATTN: Richard Meyers
Federal Systems Division
675 Prospect Street
Trenton NJ 08618-3108

General Dynamics Fort Worth Div. 1
ATTN: Gary Clark
PO Box 748, MZ 4052
Fort Worth, TX 76101-0748

General Dynamics Fort Worth Div. 1
ATTN: Mr. N. Butler
PO Box 748, MZ 2281
Fort Worth, TX 76101-0748

Boeing Commercial Airplane Co. 1
MS 74-60
Renton Technical Library
PO Box 3707
Seattle, WA 98124-2207

Boeing Aerospace Co. 1
ATTN: David Wilson
PO Box 3999, MS 2E-12
Seattle, WA 98124-2499

Mitre Corp. 1
ATTN: R. Ellis
Burlington Road, Stop H-130
Bedford MA 01730-0208

Logistics Management Institute 1
ATTN: Mr. Frans Nauta
6400 Goldsboro Road
Bethesda, MD 20817-5886

TRW 1
ATTN: J. Lee
1 Rancho Carmell, MSRC7/1406
San Diego, CA 92128-3499

General Electric Co. 1
ATTN: Lori Scoones
901 Broad St., MD 70-20
Utica, NY 13501-1501

Texas Instrument Inc. 1
ATTN: Bruce Roever
5825 Mark Dabling Blvd., MS 3703
Colorada Springs, CO 80919-2210

Raytheon Equipment Development Labs 1
ATTN: Mr. Avery Hevesh
528 Boston Post Rd., MS-5-1-669
Sudbury, MA 01776

Aerospace Corp. 1
ATTN: R. Li
PO Box 92957, MS M5/591
Los Angeles, CA 90009-2957

Aerospace Corp. 1
ATTN: K.G. Holden
PO Box 92957, M4-996
Los Angeles, CA 90009-2957

Jim Reid 1
17 Whaling Drive
Waterford, CT 06385

AT&T Bell Labs 1
ATTN: N. Robbins
Room 14C 355
Whippany, NJ 07981

Lockheed-Georgia Co. 1
ATTN: R. Lee Madison
MS D/72-49 Z-419
747 Sharp Mtn. Crk.
Marrieta, GA 30067

Lockheed Space Operations Co. 1
Attn: Robert Chase
Dept. 51-22, MC-LSO-291
PO Box 2686
Titusville FL 32780

Sutron Corp. 1
ATTN: Del Uthman
2190 Fox Mill Rd.
Herndon VA 22071

McDonnell Douglas Missile Sys Co. 1
ATTN: Mr. A. Sasaki
Dept E-261, Mailcode 1063663
PO Box 516
Saint Louis MO 63166

TRW 1
ATTN: Sam Goggin
293 Highway 247 S
Warner Robbins GA 31088

Signetics Corp. 1
Attn: Dick Lambert
4130 South Market Court
Sacramento, CA 95834

Florida Institute of Technology 1
ATTN: Professor G. F. Goldberg
Dept. of Management
150 University Blvd.
Melbourne, FL 32901

Florida Institute of Technology 1
Attn: Professor Leonard R. Doyon
440 Hawthorne Court
Indian Harbor Beach FL 32937

Florida Institute of Technology 1
Attn: Professor Frederick Buoni
Dept. of Mathematics
150 W. University Blvd
Melbourne FL 32901-6988

Sperry Corp. 1
ATTN: Eldon Goulden
4012 Calle Pino, NE
Albuquerque NM 87119-9200

Hughes Aircraft Co. 1
ATTN: A. Samuels
PO Box 902, El MS B105
El Segundo CA 90245-0902

Support Systems Associates, Inc. 1
ATTN: Bill Foreman
2465 N. Main Street/Suite 13
Sunset, UT 84015

Martin Marrietta 1
10456 W. Fremont Pl
Littleton CO 80127

Grumman Aircraft Systems 1
ATTN: Kenneth A. Haller
MS B08-14
Bethpage, NY 11714

Texas Instruments/DSEG 1
ATTN: D. Hoffman
PO Box 869305, MS 8506
Plano TX 75086

Les Corby 1
709 33rd St.
Manhattan, Beach CA 90266

Boeing Electronics Co. 1
Attn: Fatma Oliver
PO Box 3707, MS-9J-26
Seattle WA 98124

Florida Institute of Technology 1
Attn: Prof. John Hadjilogiou
Dept. of Electrical & Computer Eng
150 West University Blvd.
Melbourne FL 32901-6988

Institute of Defense Analyses 1
ATTN: Dr. Robert M. Rolfe
1801 N Beauregard St. (Skyline)
Alexandria VA 22311-1772

Boeing Military Airplanes 1
AFPRO/Det 34/MS 1520
ATTN: John Cheng
3801 South Oliver Street
Wichita KS 67210

Hughes Aircraft Co. 1
ATTN: Mr. T. Pliska
Bldg 618 MS W308
PO Box 3310
Fullerton CA 92634-3310

Westinghouse Electric Corp. 1
ATTN: Dr. A. Kahn
System Development Division
PO Box 746, MS 5380
Baltimore MD 21203-0746

IBM Corporation 1
ATTN: R.L. Leise
0306
Owego NY 13827

Reliability Training Institute 1
ATTN: Dr. T.L. Regulinski
PO Box 31113
Tuscon AZ 85751-9998

Westinghouse Def & Elec Sys Ct 1
ATTN: B. A. Bang
Friendship Site
PO Box 1521 MS 3G07
Baltimore MD 21203-1521

Lockheed Missiles & SpaceCo. 1
ATTN: L.E. Dov
Dept 0/62-91, Bldg 564
PO Box 3504
Sunnyvale CA 94088-3504

Boeing Aerospace Co. 1
ATTN: J.M. Barker
PO Box 3999, MS 2K-66
Seattle WA 98124-2499

TESTCOM Corp. 1
ATTN: D.B. Ibbett
625 S. Euclid, Suite 10
Anaheim CA 92802-1246

Noyes Data Corp. 1
ATTN: Janet Paul
Mill Road & Grand Ave
Park Ridge NJ 07656-1295

Lockheed 1
ATTN: F. Harrison
6800 Burleson Road, B-320, TO-56
Austin TX 78744-1018

Harris Corp. GASD 1
ATTN: C. Jensen
PO Box 9400, PR 59-L/6551
Melbourne FL 32902

General Electric Co. 1
ATTN: Earl Van Scooter
901 Broad Street, MD 702
Utica NY 13501-1501

Boeing Aerospace Company 1
ATTN: L. Hopkins
PO Box 3999, MS 8A-83
Seattle WA 98124-2499

Honeywell Inc., DASD 1
Rel Engr Dept 1586
9201 San Mateo Blvd NE
Albuquerque NM 87113-2227

The MITRE Corporation, MS H114 1
ATTN: T. Roome
Bedford MA 01730

UNISYS Corporation 1
Defense Systems, MS 1A18
ATTN: E.W. Edwards
Great Neck NY 11020

DAINA Corp. 1
ATTN: J. Pukite
4111 Central Ave. NE, Suite 212
Columbia Heights MN 55421

AT&T Bell Labs, Inc. 1
ATTN: A. Stolpen
Room 2A-159
Whippany Road
Whippany NJ 07981

AD/ENP 1
ATTN: Dr. Jasper Glover
Eglin AFB FL 32542-5000

AF/LE-R 1
Washington DC 20330-5130

AFALC/ERR 5
ATTN: Clyde Allison
Wright-Patterson AFB OH 45433-5001

AFHRL/LRLA 1
ATTN: Russell M. Genet
Wright-Patterson AFB OH 45433-6573

AFISC/SESD 2
ATTN: Capt. B. Bonnett
Norton AFB CA 92409-7001

AFIT/LSB 1
ATTN: Professor Virgil R. Rehg
Wright-Patterson AFB OH 45433-6583

AFLC LOC/CFWD 1
Wright-Patterson AFB OH 45433-5001

AFSC/PL 1
ATTN: Michael Zsak
Andrews AFB DC 20334-5000

AFSC/PLL 1
Andrews AFB DC 20334-5000

AFSC/PL 1
ATTN: Edmund Westcott
Andrews AFB DC 20334-5000

AFSC/XT 1
ATTN: Capt. Wienk
Andrews AFB DC 20334-5000

AFOTEC/LG4R 1
ATTN: Mr. Chamblee
Kirtland AFB NM 87117-7001

WRDC/FIEE 1
ATTN: Alan Burkhard
Wright-Patterson AFB OH 45433-6553

AFWAL/XRXA 1
ATTN: Robert Remm
Wright-Patterson AFB OH 45433-6523

AGMC/MLS 1
Newark AFS OH 43057-5475

AFWAL/AAAS 1
ATTN: George Konomos
Wright-Patterson AFB OH 45433-6523

ASD/AEGA 1
ATTN: Herb Kiesel
Wright-Patterson AFB OH 45433-6503

ASD/AXA 1
Wright-Patterson AFB OH 45433-6503

ASD/AXAE 1
ATTN: Mr. N.R. Vivians
Wright-Patterson AFB OH 45433-6503

ASD/EN 1
ATTN: Grover Cleveland
Wright-Patterson AFB OH 45433-6503

ASD/ENEGT 1
Wright-Patterson AFB OH 45433-6503

ASD/ENSII 1
ATTN: Jon Hiles
Wright-Patterson AFB OH 45433-6503

ASD/RAO 9
ATTN: T. Kindle
Wright-Patterson AFB OH 45433-6503

BMO/AWR 1
ATTN: Major Gary Jungwirth
Norton AFB CA 92409-6468

BMO/ALN 1
Norton AFB CA 92409-6468

Defense Product Standards Office 1
ATTN: John Wyatt
5203 Leesburg Pike, Suite 1403
Falls Church VA 22041-3466

DOD PESO C/O DLA 1
ATTN: Zabielski
Cameron Station
Alexandria VA 22314

ESD/FASE 1
ATTN: E. Sarkisian
Hanscom AFB MA 01731-5000

ESD/FAW 1
ATTN: George Oko
Hanscom AFB MA 01731-5000

ESD/OCBE 1
ATTN: Thomas Sheridan
Hanscom AFB MA 01731-5000

ESD/OCSR 1
ATTN: O. DiMarca
Hanscom AFB MA 01731-5000

ESD/SCS-1EA 1
ATTN: Helen Baker
Hanscom AFB MA 01731-5000

ESD/TCJE 1
ATTN: G. Harn
Hanscom AFB MA 01731-5000

ESD/TCS-2A 1
ATTN: David Kenyon
Hanscom AFB MA 01731-5000

ESD/TCVS 1
ATTN: R. Neil Hansen
Hanscom AFB MA 01731-5000

ESD/PL 1
Hanscom AFB MA 01731-5000

National Institute of Stds & Tech 1
ATTN: Mr. Robert E. Nelson
Div. 724.00
325 Broadway
Boulder CO 80303

Naval Air Engineering Center 1
ATTN: Jerry L. Kunert
Code 09R
Lakehurst NJ 08733-5100

Naval Air Systems Command 1
ATTN: Merlin P. Walters
Air 51652
Washington DC 20361-5110

Naval Avionics Center 1
D/410
6000 East 21st Street
Indianapolis IN 46219-2189

Naval Coastal Systems Center 1
Code 3250
Panama FL 32407

Naval Sea Systems Command 1
ATTN: William Shapleigh
Code SEA 004
Washington DC 20362-5101

Naval Ocean Systems Center 1
Attn: Mel Nunn
Code 936
San Diego CA 92152-5000

Naval Post Graduate School 1
ATTN: Professor M. B. Kline
Code 54KX
Monterey CA 93943

Naval Research Laboratory 1
ATTN: Dr. Harry Ascher
Code 1206
Washington DC 20375-5000

Naval Ship Weapons Engineering Sta. 1
Attn: Bill Flothmeier
Code 4713
Bldg 1153
Port Hueneme CA 93043-5007

Naval Surface Weapons Center 1
ATTN: William L. Keiner
Code E302
Dahlgren VA 22448-5000

Naval Training Equipment Center 1
Attn: George Campbell
Code N411
Orlando FL 32813-7100

Naval Underwater Systems Center 1
ATTN: R. A. Pikul
Code 434
Newport RI 02841-5047

Naval Underwater Systems Center 1
ATTN: William Crimmins
Newport RI 02841-5047

Naval Underwater Systems Center 1
ATTN: James Souza
Code 3654
Bldg. 148
Newport RI 02841-5047

OC-ALC/MME 1
Tinker AFB OK 73145-5979

OO-ALC/MMEAR 1
Hill AFB UT 84056-5990

OASD(P&L)PS/SDM 1
ATTN: Peter Yurcisin
Room 2A318
Pentagon
Washington, DC 20301-8000

OUSD R&E 1
Director of Elect & Phys. Sci.
Pentagon, Room 3D1079
Washington DC 20301

RADC/CO 1
Griffiss AFB NY 13441-5700

RADC/DC 1
Griffiss AFB NY 13441-5700

RADC/EE 1
Hanscom AFB MA 01731-5000

RADC/ES 1
Hanscom AFB MA 01731-5000

RADC/IR 1
Griffiss AFB NY 13441-5700

RADC/OC 1
Griffiss AFB NY 13441-5700

SA-ALC/MMEA 1
Kelly AFB TX 78241-5990

SA-ALC/MMTMA 1
ATTN: Joseph Johnson
Kelly AFB TX 78241-5990

SA-ALC/MMIRAP 1
ATTN: Paul Reed
Kelly AFB TX 78241-5990

SD/ALTR 1
ATTN: Mr. Leese
Worldway Postal Center
PO Box 92960
Los Angeles CA 90009-2960

SM-ALC/MME 1
McClellan AFB CA 95652-5990

US Army Aviation Systems Command 1
ATTN: Mr. Payne
AMSAB-QR
4300 Goodfellow Blvd.
St. Louis MO 63120-1798

US Army Comm-Elect Cmd. 1
ATTN: R. Jupinka
DRSEL-PA-RJ
Fort Monmouth NJ 07703-5000

US Army Comm-Elect Cmd. 1
ATTN: Hoffman
DRSEL-PA-M
Fort Monmouth NJ 07703-5000

US Army LABCOM ET&D Laboratory 1
ATTN: Dr. C.G. Thornton
SLCET-D
Fort Monmouth NJ 07703-5302

US Army Logistics Evaluation Agency 1
Attn: Daveau
DALO-LEI
New Cumberland Army Depot
New Cumberland PA 17070-5001

US Army Logistics Management Ct. 1
Attn: Mr. Sampson
Def. Logistics Studies Info. Exch.
Fort Lee, VA 23801-6043

Belvoir, Research & Development Ct. 1
ATTN: Mr. Rabon
DRDME-TQ
Fort Belvoir VA 22060-5606

US Army R&T Laboratories (AVRADCOM) 1
ATTN: Mr. Poteate
DAVDL-ATL-ASR
Applied Technology Laboratory
Fort Eustis VA 23604-5577

WR-ALC/MME 1
Robins AFB GA 31098-5609

WR-ALC/MMIR 1
Robins AFB GA 31098-5609

WR-ALC/MMRR 1
Robins AFB GA 31098-5609

National Security Agency 1
Attn: Mr. W.W. Vinson
R151
9800 Savage Road
Fort Meade MD 20755-6000

AFALC/PTEC 1
ATTN: Capt. Steve Burke
Wright-Patterson AFB OH 45433-5001

National Security Agency 1
Attn: Frederick W. Pankow
T2113
Fort George G. Meade MD 20755-6000

Naval Warfare Assessment Center 2
ATTN: R. Monroe
Code 3143
Test Technology Information Center
Corona, CA 91720-5000

Naval Warfare Assessment Center 2
ATTN: M. Kaufman
Code 3143
Test Technology Information Center
Corona, CA 91720-5000

NASA/MSFC 1
ATTN: Felminio Villella
Dept. EB 13/Bldg. 4487
Huntsville AL 35812

OC-ALC/MMEA 1
Tinker AFB OK 73145-5979

OC-ALC/MMIR 1
Tinker AFB OK 73145-5989

US Army Comm-Elect Cmd. 1
Attn: J. Argios
DRCPM-TMDE-L
Fort Monmouth NJ 07703-5000

SM-ALC/MAITC 1
ATTN: C. Wayne McNally
McClellan AFB CA 95652-5990

ASD/AFES 1
ATTN: James L. Koenig
Wright-Patterson AFB OH 45433-6503

AFIT/LSQ 1
ATTN: Capt Clinton Cambell
Wright-Patterson AFB OH 45433-6583

OSAF/ALG 1
ATTN: Mr. Oscar Goldfarb
Washington DC 20330-1000

ASD/AEGE 1
ATTN: J. Stout
Wright-Patterson AFB OH 45433-6503

FAA 1
Attn: Mr. Robert Hodge
APM 610
800 Independence Ave.
Washington, DC 20591

FAA Technical Center 1
Attn: Nickolus O. Rasch
ACT-340
Atlantic City Airport, NJ 08405

National Security Agency 1
ATTN: John Chriest
Y211
Fort George G. Meade, MD 20755-6000

ASD/AFES 1
ATTN: Mr. Dean Edgemon
Wright-Patterson AFB OH 45433-6503

OASD (MI&L) Martin A. Meth 1
Pentagon, Room 2B322
Washington DC 20301

US Army Mgt Eng. Training Act. 1
ATTN: Mr Jerold Nelson
AMXOM-QA
Rock Island, IL 61299-7040

US Army Mgt Eng. Training Act. 1
ATTN: Mr. Raymond Loecke
AMXOM-QA
Rock Island, IL 61299-7040

Naval Warfare Assessment Center 1
ATTN: Mr. Allan Burkholder
MC 3432
Corona, CA 91720-5000

HQ AFLC LOC/TL 1
ATTN: Col Fredric Abrams
Wright-Patterson AFB OH 45433-5001

WR-ALC/MMRRAH 1
Robert Gault
Robins AFB, GA 31098-5609

WR-ALC/MAITAB 1
ATTN: Jerry Johnson
Robins AFB, GA 31098-5149

Director, USAMSAA 1
ATTN: P. Ellner
AMXSY-RM
Aberdeen Proving Gd, MD 21005-5055

ASD/EN (PA) 1
Wright-Patterson AFB OH 45433-6503

WR-ALC/MMRRAH 1
ATTN: Ed Fransioli
Robbins AFB, GA 31098-5609

US Air Force Academy 1
ATTN: Capt. James A. Doyless
Department of Management
Colorado Springs, CO 80840-5941

Naval Underwater Systems Center 1
ATTN: Mandeep Nehra
Code 434, Bldg. 102
Newport, RI 02841-5047

OC-ALC/MMKRB 1
ATTN: John Hertz
Tinker AFB, OK 73145-5990

Navy Space Program Detachment 1
ATTN: Paul F. Babcock
Code 32
Warner Robbins AFB GA 31088

RADC/LW 1
ATTN: Lt Col Liska
Griffiss AFB 13441-5700

Commander 1
Naval Air Systems Command
ATTN: John Wilson
Advanced Platform APML
Washington DC 20361-4110

Industrial Prod Support Office 1
ATTN: Kurt Greene
c/o Defense Logistics Agency
Cameron Station
Alexandria, VA 22304-6183

Naval Avionics Center 1
ATTN: Gene Keeler
Code B918
6003 E 21st Street
Indianapolis, IN 46219-2189

USAFA Reliability Studies Group 1
ATTN: Maj R. Sheldon
Department of Mathematics
USAF Academy, CO 80840-5000

ASD/ENE(GIMADS) 1
ATTN: D.F Wilkerson
Wright-Patterson AFB OH 45433-6503

ESD/PLET 1
ATTN: Capt. Mike Newman
Hanscom AFB MA 01731-5000

AFIT/LSQ 1
ATTN: C. Widenhouse
Wright-Patterson AFB OH 45433-6583

HQ AFSPACECOM/LKYY 1
ATTN: Capt. David Wile
Peterson AFB CO 80914-5001

ESD/AVBA 1
ATTN: Larry Kriger
Hanscom AFB MA 01731-5000

ESC/XPEN 1
Attn: Mr. A. Lopez
San Antonio TX 78243

The Analytic Sciences Corp. 1
Attn: Mr. James Kelly
1 Jacob Way
Reading, MA 01867

DAINA Corporation 1
Attn: Janis Pukite
4111 Central Ave. N.E.
Suite 212
Columbia Heights, MN 55421

Lockheed Aeronautics Systems 1
Attn: Bill Ng
Dept. 7072 Bldg 65 Plant A1
P.O. Box 551
Burbank, CA 91520-7072

ANSER Corp. 1
Attn: Melanie Crotty
Suite 800
1215 Jefferson Davis Hwy
Arlington VA 22202

Boeing Aerospace Corp. 1
Attn: William Buckingham
P.O. Box 3999, MS 2E-10
Seattle, WA 98124-2499

University of Washington 1
Attn: Arun Somani
Dept. of Electrical Engineering
Seattle, WA 98195

Northrup Corp./B-2 Division 1
Attn: Clyde Denison
L103/IN Advanced Projects
3900 E. Washington BLVD
Pico Rivera, CA 90660-3737

Institute for Defense Analysis 1
Attn: Mitch Robinson
Strategy, Forces, and Resources Div
1801 N. Beauregard Street
Alexandria, VA 22311

Boeing Commercial Airplanes 1
Attn: Tilak Sharma
P.O. Box 3707
M/S 7Y-21
Seattle, WA 98124-2207

MISSION

of

Rome Air Development Center

RADC plans and executes research, development, test and selected acquisition programs in support of Command, Control, Communications and Intelligence (C^3I) activities. Technical and engineering support within areas of competence is provided to ESD Program Offices (POs) and other ESD elements to perform effective acquisition of C^3I systems. The areas of technical competence include communications, command and control, battle management information processing, surveillance sensors, intelligence data collection and handling, solid state sciences, electromagnetics, and propagation, and electronic reliability/maintainability and compatibility.